EQUIPMENT
THEORY FOR
RESPIRATORY
CARE

4th Edition

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THOMSON

DELMAR LEARNING

Equipment Theory for Respiratory Care, Fourth Edition
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NOTICE TO THE READER

CHAPTER 1

MEDICAL GAS SUPPLY EQUIPMENT

INTRODUCTION

Administration of medical gases is involved in most of the tasks performed by a respiratory care practitioner. It is important to understand how the supply equipment for oxygen therapy and mixed-gas therapy operates and how to troubleshoot these devices when problems arise.

In this chapter you will study the physics of equipment operation, focusing especially on gas supply systems. Only by thoroughly understanding the equipment and its components can you safely use it and troubleshoot it if it fails to function properly.

OBJECTIVES

After completing this chapter, the student will accomplish the following objectives:

PHYSICS OF THE PRINCIPLES

- Describe the kinetic theory of gases.
- Define the term *gas pressure*; explain what causes it and how it is measured.
- Explain Pascal's law.
- Explain what causes gases to flow from one place to another and how gas flow is measured.
- Explain Bernoulli's principle.
- Describe the principle of viscous shearing and vorticity.
- Explain how ejectors work:
  — in conjunction with venturi tubes
  — with constant area ducts
- Describe choked flow and the conditions under which it occurs.
- Explain the significance of Reynolds' number.
- Apply the following laws to solve for volume, temperature, or pressure:
  — Boyle's law
  — Charles' law
  — Dalton's law
  — Gay-Lussac's law
  — Combined or ideal gas law

  — Fick's law
  — Henry's law
  — Graham's law

MEDICAL GAS SUPPLY EQUIPMENT

- Differentiate between the following supply systems; describe their construction and their principles of operation:
  — cylinders
  — liquid reservoirs, including calculation of oxygen duration based on weight
  — piping systems
  — compressors
  — concentrators
- Identify the contents of a medical gas cylinder, using the U.S. and international color code system, for the following gases:
  — oxygen
  — carbon dioxide
  — nitrous oxide
  — cyclopropane
  — helium
  — carbon dioxide and oxygen
  — helium and oxygen
  — air
- Given an oxygen "E" or "H" cylinder, gauge pressure and liter flow, calculate how long the cylinder will last.

- Identify the markings stamped on the cylinder shoulder.
- List fifteen rules established by the Compressed Gas Association and the National Fire Protection Association for the safe storage and handling of compressed medical gas cylinders.
- Differentiate between the following oxygen regulation devices; describe their construction and principles of operation:
  — direct-acting cylinder valve
  — indirect-acting cylinder valve
  — single-stage reducing valve

  — modified single-stage reducing valve
  — multiple-stage reducing valve
  — regulator
  — oxygen proportioner
  — demand pulse-flow regulators
- Differentiate between the following oxygen flowmeters; describe their construction and principles of operation:
  — Bourdon gauge
  — uncompensated Thorpe tube
  — compensated Thorpe tube
  — fixed orifice flowmeter

KEY TERMS

Absolute temperature	Choked flow	Henry's law	Pressure
Adsorption	Combined gas law	Kinetic theory	Reducing valve
Aneroid barometer	Compressors	Laminar gas flow	Regulator
Bernoulli's principle	Dalton's law	Manifold	Reynolds' number
Blender	Diaphragm compressors	Mechanical manometer	Thorpe tube flowmeter
Bourdon gauge	Direct acting cylinder valve	Membrane enricher	Torr
Bourdon gauge flowmeter	Ducted ejector	Mercury barometer	Turbulent gas flow
Boyle's law	Fick's law	Molecular sieve concentrator	Venturi mask
Brownian motion	Fixed orifice flowmeter	Oxygen concentrator	Viscous shearing
Centrifugal compressor	Gay-Lussac's law	Oxygen conserving device (OCD)	Zone valves
Charles' law	Graham's law	Poiseuille's law	

PHYSICS OF THE PRINCIPLES

BEHAVIOR OF GASES

Gases behave according to the **kinetic theory.** The kinetic theory describes the behavior of ideal gases, and it incorporates five important points. These points are: (1) gases are composed of discrete molecules; (2) the molecules are in random motion; (3) all molecular collisions are elastic, causing no energy transfer between molecules; (4) the molecular activity is directly dependent upon the temperature; and (5) there is no physical attraction between the molecules composing the gas.

Gases are composed of very small, discrete molecules. The distance between molecules is much greater than the actual diameter of the individual molecules. Therefore, gases consist of large amounts of open space between the

gas molecules. The volume of the molecules (if they could be gathered together) is very small when compared to the total volume of the molecules and space as a whole.

Gas molecules are in constant, random motion. The molecules travel in a straight line or path. This motion continues until they collide with something else. These collisions can occur with other molecules, the walls of the container holding the gas, or other particles. Evidence of these collisions was first described by Robert Brown in 1827. He described the motion of larger particles that moved as a result of the smaller molecules of the gas colliding with them. This random movement can be observed today by watching the behavior of cigarette smoke under a microscope. The random motion of the larger particles is termed **Brownian motion**.

The collisions between molecules are completely elastic. This means that there is no energy transferred as a result of these collisions. Energy is not lost or gained by the mole-

cules as a result of this process. Therefore, the total energy of the gas remains constant.

The kinetic activity or speed of the molecules is largely determined by the temperature. As the temperature of a gas increases, so does the kinetic activity. Conversely, as the temperature of a gas decreases, its kinetic activity decreases.

In ideal gas behavior, the gas molecules do not attract or repel one another. There is no physical attractive force between individual molecules. The molecules move about freely without any significant attractive forces between them.

GAS PRESSURE

Causes

Gas **pressure** (force per unit area) is caused by the individual gas molecules colliding with one another and the walls of a container. This exerts a force on the container walls. Even gas molecules have mass and a velocity, and thus possess a certain momentum (momentum = mass × velocity). The momentum transferred from these multiple collisions is what creates pressure, or the force on the walls of a container. The temperature of a gas influences the level of kinetic activity and therefore the velocity of the molecules.

Pascal's Law

Blaise Pascal, a seventeenth-century investigator, described how force is transmitted in a fluid. Pascal discovered that a fluid confined in a container will transmit force or pressure uniformly in all directions and that the pressure, or force at the walls of the container, acts perpendicular to that surface.

Since gases behave according to fluid properties, Pascal's law also applies. Pressure at any point in a closed container is equal to the pressure at any other point in the same container. If you take a long, closed tube and pressurize it with a gas, the pressure at one end will be equal to the pressure at the opposite end. Also, the pressure acts equally in all directions, with the force applied perpendicular to all surfaces of the tube.

Measurement of Gas Pressure— Barometers

The atmospheric pressure is measured with an instrument called a barometer. There are two types of barometers, mercury and aneroid.

The **mercury barometer** uses the weight of a column of mercury opposing the force of the atmosphere to measure atmospheric pressure (Figure 1-1). The barometer consists of a closed column of mercury inverted in a shallow reservoir open to the atmosphere. When the column is inverted in the reservoir, a vacuum is created as gravity pulls the column of mercury down from the top of the closed tube. Atmospheric pressure against the open reservoir balances the gravitational force, pushing the mercury upward in the closed tube. The level of the mercury column rises or falls, depending upon the atmospheric pressure exerted against the open reservoir. A calibrated scale adjacent to the mercury column provides a method to measure the height of the column of mercury. For medical and scientific purposes, atmospheric pressure is measured in millimeters of mercury. This measurement is also referred to as **torr** (named after Evangelista Torricelli, the inventor of this barometer).

The **aneroid barometer** (Figure 1-2) consists of an evacuated metal container that has a pressure lower than atmospheric pressure. A spring is attached between the container and a pointer mechanism. This indicates the pressure. As gas pressure increases, the container is compressed. This causes the pointer to move, indicating an increased pressure. The pointer moves adjacent to a scale calibrated in millimeters of mercury.

MERCURY COLUMN

CALIBRATED SCALE
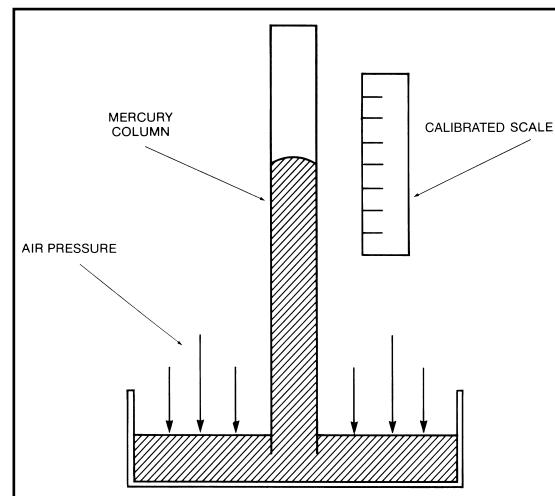
AIR PRESSURE

Figure 1-1 *A full section of a mercury barometer. Note how air pressure causes the mercury column to rise in the vertical tube.*
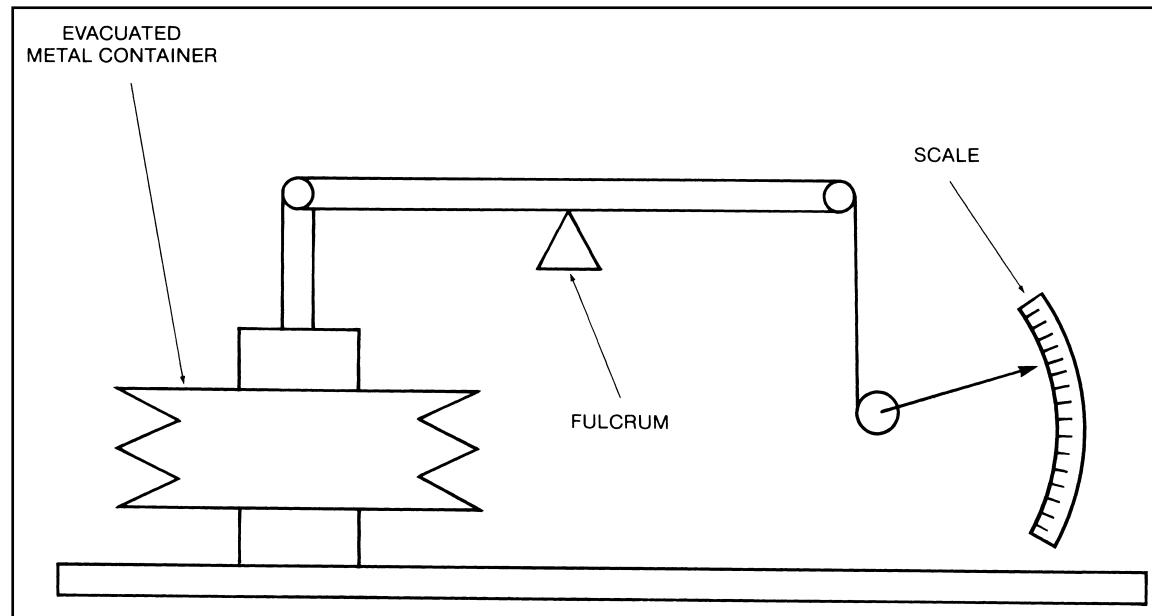
Figure 1-2 *A functional diagram of an aneroid barometer. As air pressure causes the evacuated container to expand or contract, the pointer moves adjacent to the scale.*

Measurement of Gas Pressure— Other Devices

In addition to barometers, mechanical manometers and Bourdon gauges can be used to measure gas pressure. A **mechanical manometer** (Figure 1-3) is similar in construction to an aneroid barometer. A diaphragm or evacuated container is exposed to the area where pressure measurement is desired. As gas exerts a force against the diaphragm or container, it causes the pointer's position to change, indicating the pressure. Note that these instruments are calibrated so that atmospheric pressure measures zero on the instrument's scale. The majority of manometers in respiratory care are calibrated in centimeters
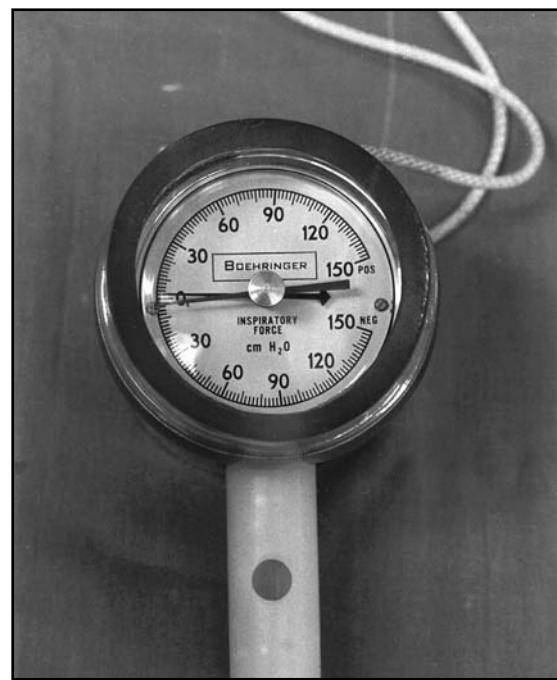
(A)
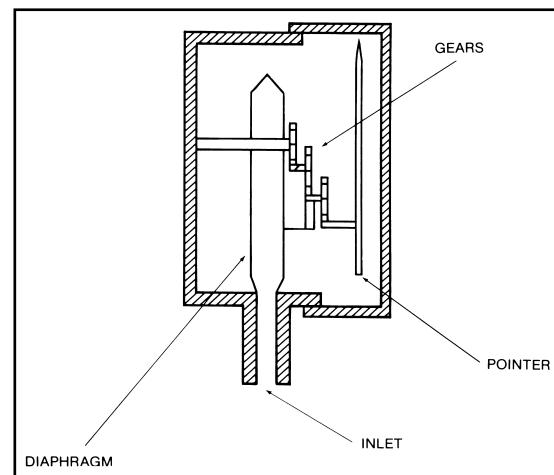
(B)

Figure 1-3 *A photograph and functional diagram of an inspiratory force manometer. As pressure causes the evacuated container to expand or contract, the pointer moves adjacent to its scale.*

of water pressure or Kilopascals (KPa) (le Système International d'Unités [si], or metric units). Table 1-1 lists standard units of pressure measurement.

A **Bourdon gauge** (Figure 1-4) consists of a hollow coiled metal tube with an elliptical cross section that is exposed to an area where gas pressure measurement is desired. Attached to the coiled tube are a gear mechanism and a pointer. As pressure increases, the tube begins to straighten, causing the gears to turn and the position of the pointer to change. The tube straightens because the pressure causes the cross section of the tube to become rounder. As the cross section changes, the outside of the tube is stretched while the inside becomes compressed. These gauges are commonly found on medical gas cylinders, indicating the pressure inside of the cylinder, and are calibrated in pounds per square inch (psi).

GAS FLOW

Cause

Gas flows from one point to another due to a difference in pressure between the two points. Gas will flow from an area of greater pressure to an area of lower pressure. The area of greater pressure contains gas molecules with greater kinetic activity. As a result of the increased kinetic activity (energy), the molecules push

TABLE 1-1 Units of Pressure Measurement

Unit		Equivalent
1 Atm	=	760 mm Hg
		29.921 in Hg
		1034 cm H_2O
		101.325 KPa
		14.7 lb/in^2
1 cm H_2O	=	.735 mm Hg
		.0142 lb/in^2
1 mmHg	=	1.36 cm H_2O
		.019 lb/in^2
1 KPa	=	.133 mm Hg
		.098 cm H_2O
		6.895 lb/in^2
1 lb/in^2	=	51.7 mm Hg
		70.34 cm H_2O
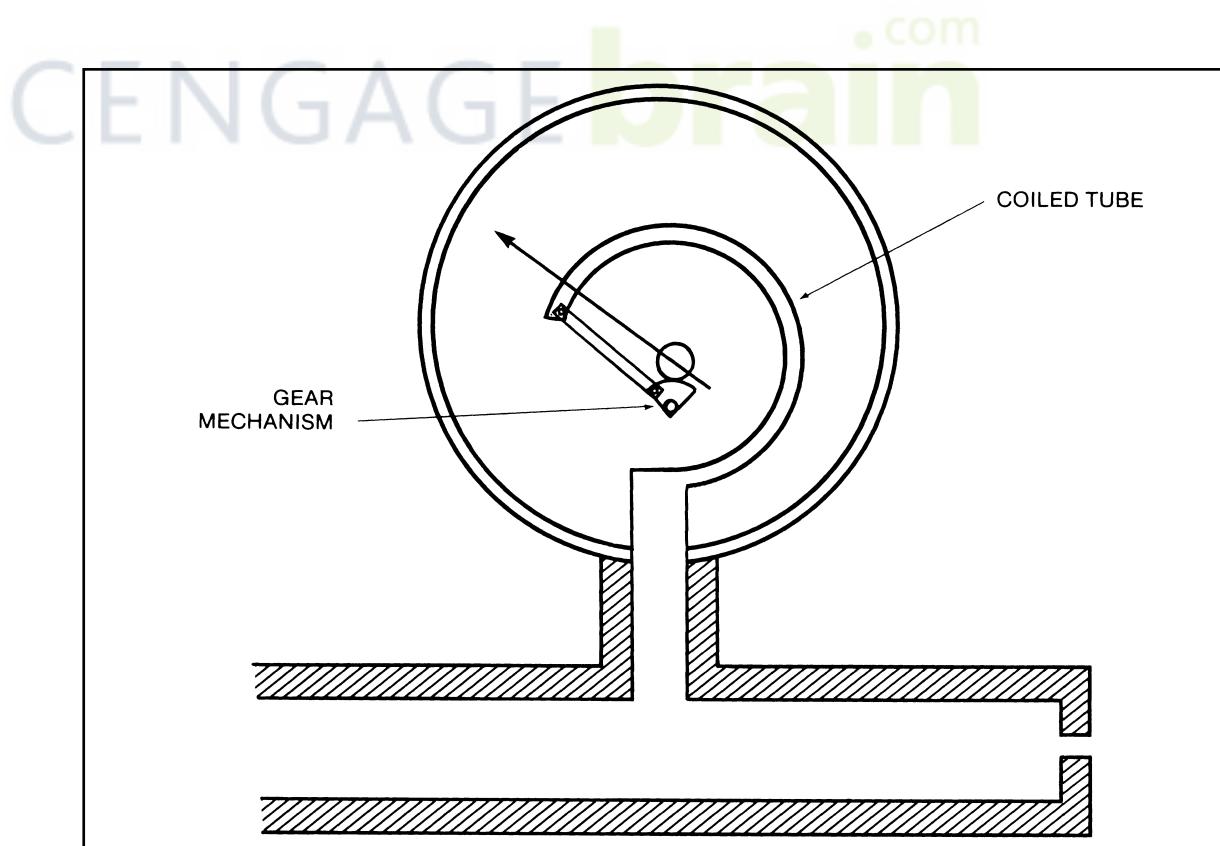
Figure 1-4 *A functional diagram of a Bourdon gauge. As the coiled tube expands, the gear mechanism rotates, causing the pointer to move.*

one another, moving from the area of higher energy to the area of lower energy.

The rate of gas flow, or velocity, is dependent on two factors: the difference in pressure (energy) and the size of the opening between the two areas. If the pressure difference is large, gas flow will be faster. If the pressure difference is small, gas flow will be slower. If the opening between the two areas is large, more gas can pass through and the flow will be greater than if the opening is small (Figure 1-5).

Bernoulli's Principle

During the eighteenth century, Daniel Bernoulli studied the flow of gas through tubes. He discovered that as the velocity of a gas increases, the lateral pressure within the tube decreases. This is due to the fact that the total energy content of the gas is constant. The total energy of the gas results from the kinetic energy created by the velocity and pressure energy. As velocity increases, the pressure must decrease for the total energy to remain constant (conservation of energy). As gas flow increases, more of the gas's energy is contained in kinetic energy, causing a further reduction in lateral pressure (Figure 1-6). In this application, **Bernoulli's principle** applies to the flow of gas within a tube that changes in
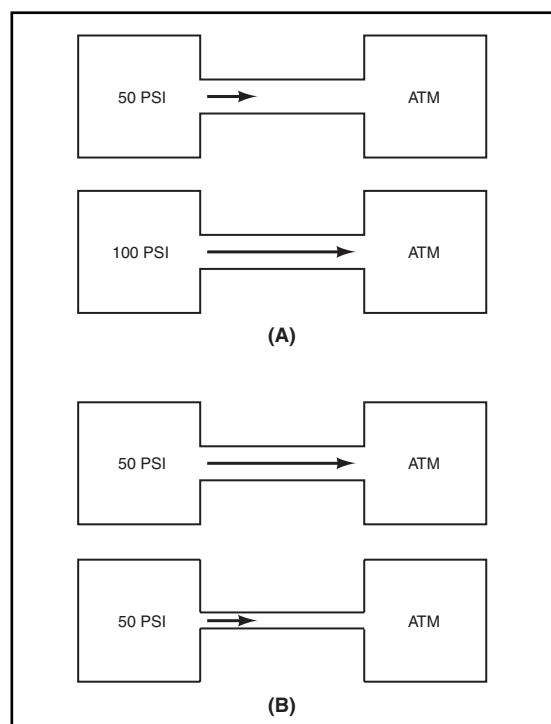
Figure 1-5 *Factors influencing gas flow: (A) two different pressures; (B) two different orifice sizes.*

area along its length. A cross-sectional change is required to change the velocity. Bernoulli's equation assumes that the fluid is incompressible, that is, that the specific weight (weight
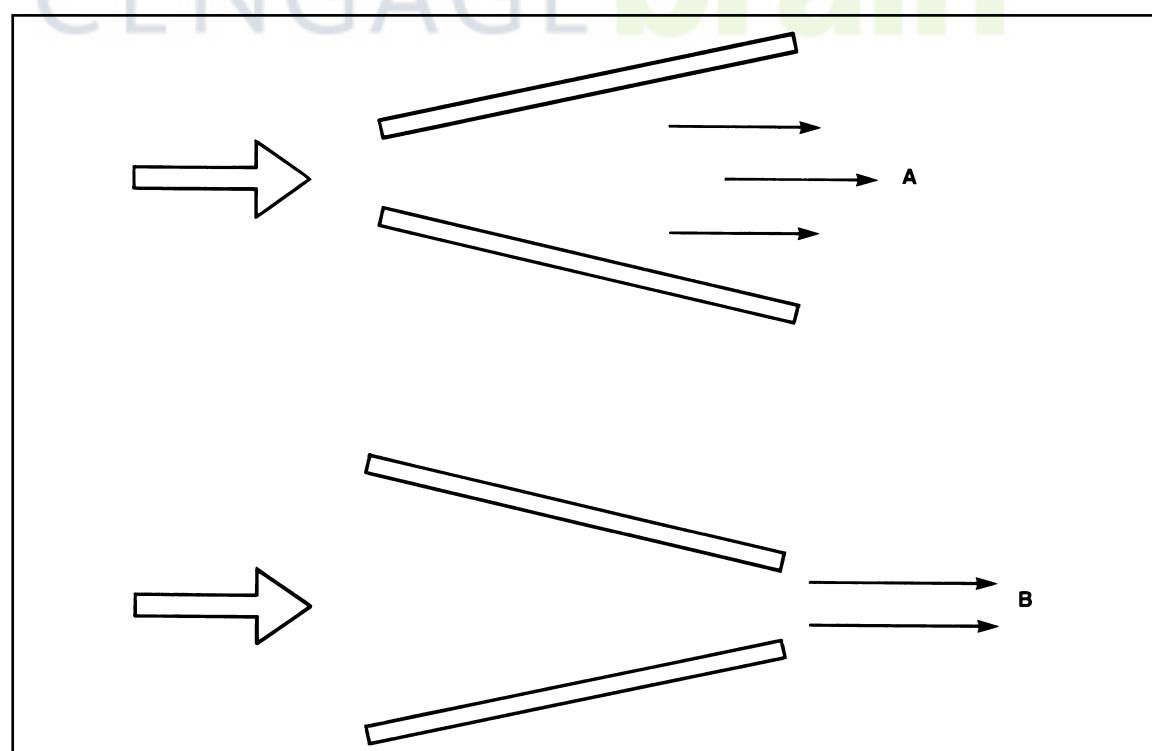
Figure 1-6 *Diverging and converging ducts: (A) the diverging duct slows the velocity and increases the pressure; (B) the converging duct increases the velocity and decreases the pressure.*

per unit volume) is constant. If the fluid were to be compressed, volume would decrease while the weight would remain constant, increasing the specific weight. Keep in mind that gases will remain incompressible at low velocities, generally less than 100 meters per second.

This principle is commonly applied in respiratory care equipment. The reduced pressure within the tube may be used to introduce gases (usually air) or liquids into a low-pressure region of gas flow.

VISCOUS SHEARING, VORTICITY, AND EJECTORS

Viscous shearing is another means by which oxygen is mixed with ambient or stationary air. **Viscous shearing** occurs when a high-velocity jet is injected into a quiescent gas. The high-velocity gas from the jet forms a thin boundary layer, where frictional forces develop between the high-velocity gas and the stationary surrounding air, cleaving it (Figure 1-7). The rapidly flowing gas accelerates the stationary gas, while the stationary gas decreases the velocity of the jet. Shear forces develop along the boundary layer between the two gases. The decelerating, high-velocity jet forms vortices, which envelop the ambient air, along the boundary layer. The viscous shearing effect entrains the room air into the vortices, mixing the oxygen with it. By varying the size of the oxygen jet and the entrainment ports, differing oxygen concentrations can be obtained. Manufacturers have developed specific combinations of entrainment ports and jet sizes to deliver precise F_IO_2 levels. This principle is applied in *High Air Flow with Oxygen Enrichment (HAFOE)* masks, commonly called "**venturi masks**."

Venturi's Principle

Venturi expanded Bernoulli's principle by adding a specially shaped tube downstream from the jet. This tube has an increasing radius such that the angle of the walls does not exceed 15 degrees (Figure 1-8A). Note the pressure curve as gas passes through the tube. Pressure is reduced in the center and, due to the Bernoulli effect, progressively increases as the diameter of the tube increases near the outlet (Figure 1-8B). The high velocity of the gas from the nozzle causes ambient air to be mixed with the gas from the nozzle (by viscous shearing and vorticity, described earlier in this chapter), adding to the total quantity of gas flowing through the tube. As the tube expands, gas velocity slows and pressure increases. Venturi tubes are often employed where gas flow can be increased through entrainment of ambient air. Due to the Bernoulli effect, gas velocities through venturi tubes are generally low.

Constant Area Duct

This type of **ducted ejector** is similar to a venturi tube except that instead of restoring lateral pressure, the tube's purpose is to maintain a high velocity following the jet or restriction.

The ejector consists of a straight-walled tube that does not change in diameter downstream from the jet. Gas is entrained at the entrance to the tube (due to viscous shearing and vorticity between the source gas and ambient air) increasing total flow through the device. The tube downstream from the jet shields the flow of gas from entrainment without significantly slowing the velocity of the gas through the device (Figure 1-9). Velocity remains high and pressure remains constant
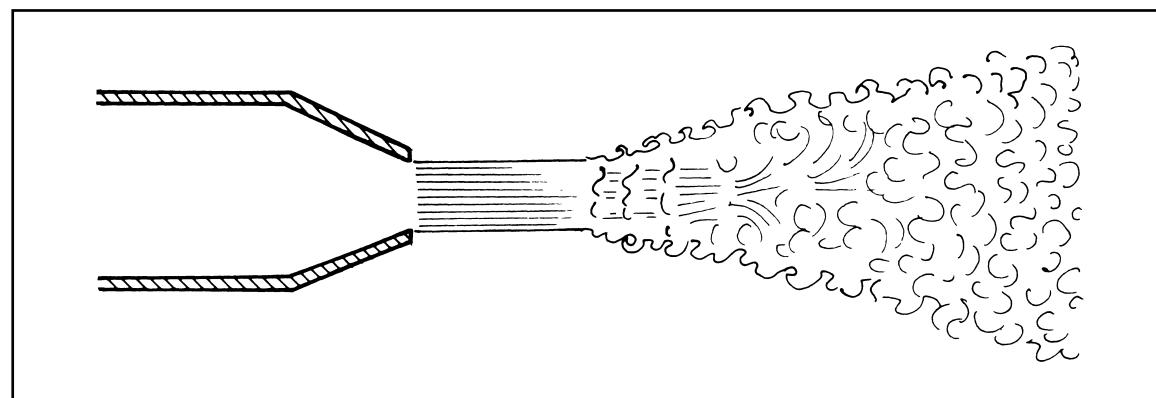
Figure 1-7 *The principle of viscous shearing. Note how the quiescent gas reduces the high velocity of the gas stream through the formation of vortices.*
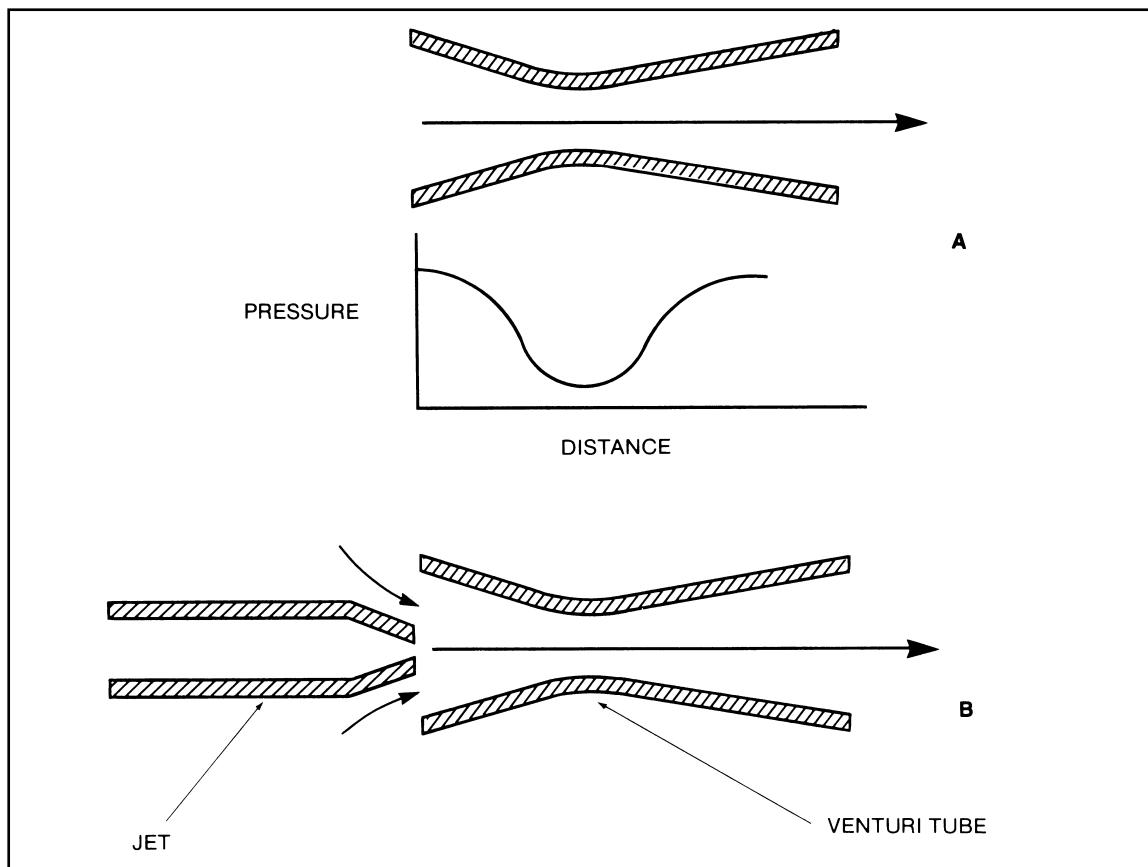
Figure 1-8 *Venturi's principle: (A) an illustration of the pressure gradient through a venturi tube; (B) a functional diagram of a nozzle combined with a venturi tube to form an ejector.*
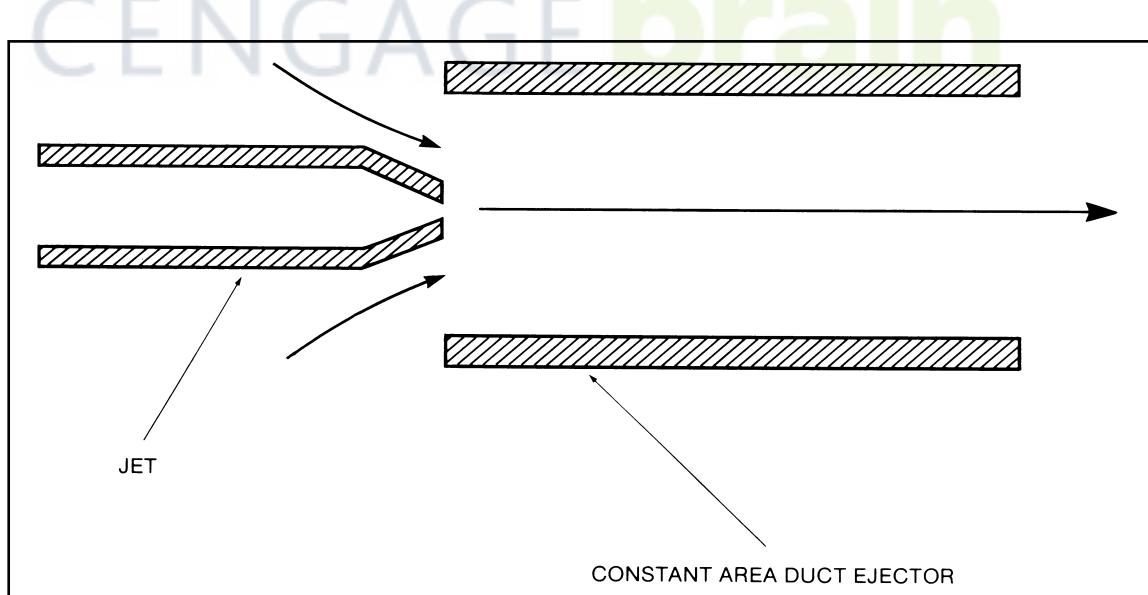
Figure 1-9 *A functional diagram of a constant-area duct ejector.*

because the diameter of the tube is constant (unlike the venturi tube). An advantage of this device is that an increased pressure downstream from the straight-walled tube has less effect on gas entrainment than with a venturi tube. These devices are employed in nebulizers and oxygen/air entrainment devices where there is moderate resistance downstream from the tube.

Effects of Increased Distal Pressure on Venturi and Constant Area Ducts

An increase in pressure downstream from an ejector will decrease the amount of ambient air entrainment. An increase in pressure may be caused by a kink in the delivery tubing or an obstruction distal to the point of air entrainment. This increase in pressure distal to the jet results in less ambient air entrainment because the total flow through the tube decreases as the back pressure increases. The flow through the jet's nozzle is constant; thus, the entrainment must decrease (Figure 1-10).

CHOKED FLOW OR COMPRESSIBLE FLOW

When a gas is flowing through an orifice or nozzle, the velocity of the gas increases as the pressure upstream (head pressure) of the nozzle increases. When the head reaches pressure 1.893 times the atmospheric pressure for air, the velocity of the gas no longer increases and the flow is choked. This corresponds to sonic flow at the orifice of the jet, which for air at room temperature is approximately 347 meters per second. This velocity corresponds to the speed of sound in air at room temperature. Once the gas reaches sonic velocity, the gas's velocity can no longer increase. Increasing the head pressure will not result in an increased flow when the flow is choked. The behavior of **choked flow** may be predicted using the choked flow equation, but this is beyond the scope of this text.

Choked flow is used in nebulizers when the head pressure driving the jet exceeds 26 psi, making the gas velocity out of the nozzle's exit sonic. Liquids are drawn into the gas flow from the reservoir via the capillary tube at the boundary layer by shear forces and vorticity.

When these high-velocity jets are used in ventilators, the gas flow downstream from the nozzle at a distance of approximately three times the diameter of the nozzle exit ceases to be well behaved or laminar. At this point a shear layer develops and ambient gas may be entrained by vorticity. When used in this application, these jets are sometimes referred to as injectors, although the term ejector is technically more correct. If designed properly, the flow output from an ejector will exceed the flow provided by the nozzle alone.

Reynolds' Number

Reynolds' number is used to determine if gas flow through a tube is laminar or turbulent. **Laminar gas flow** is a smooth, uniform flow that requires less energy (pressure) to sustain. **Turbulent gas flow** is more erratic and irregular, requiring more energy to sustain. Figure 1-11 compares turbulent and laminar
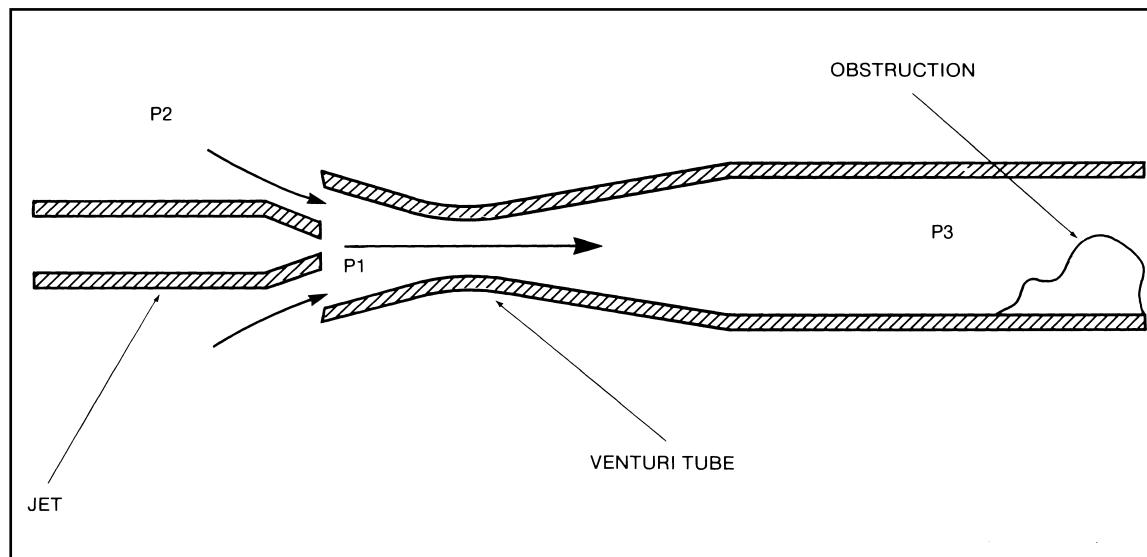
Figure 1-10 *An obstruction can result in decreased air entrainment through a venturi tube. P1 is less than P2 (atmospheric), and the obstruction causes P3 to be greater than P2. Note that the obstruction increases pressure distal to the entrainment ports, thus decreasing gas entrainment.*
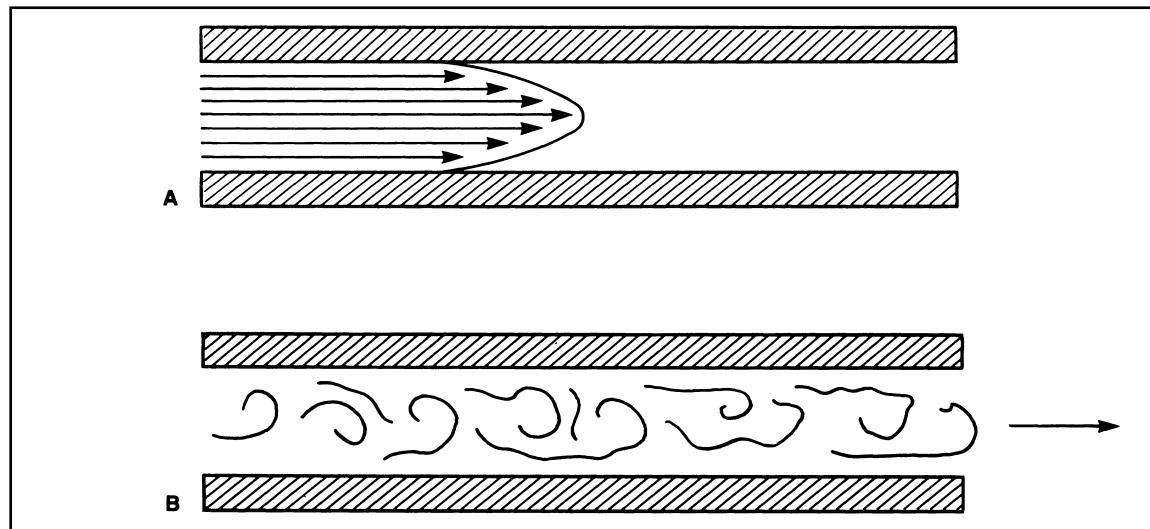
Figure 1-11 *(A) Laminar and (B) turbulent gas flow.*

gas flow. The Reynolds' number formula is as follows:

$$R_e = \frac{(Velocity)(Density)(Diameter)}{Viscosity}$$

R_e = Reynolds' number

Note that if you include the correct units in the calculation of Reynolds' number, the units cancel one another, resulting in a number that is dimensionless. As a general rule, if the Reynolds' number is greater than 2000, flow will be turbulent. If the Reynolds' number is less than 2000, flow will be laminar.

Poiseuille's Law

Poiseuille described the resistance to the flow of gas or liquid through a tube when the flow is laminar. He determined that it is directly related to volumetric flow, length of the tube and viscosity of the gas, and inversely related to the radius of the tube to the fourth power. This law is generally expressed in the following formula:

$$\dot{V} = \frac{\Delta P(\pi)(r^4)}{8(l)(\mu)}$$

$\dot{V}$ = volumetric flow rate (velocity × area)
ΔP = pressure gradient
π = 3.1415
r = radius of the tube
μ = viscosity of the gas
l = length of the tube

Resistance is equal to the change in pressure divided by the volumetric flow rate.

Solving Poiseuille's law for resistance:

$$R = \frac{\Delta P}{\dot{V}}$$

$$R = \frac{8(l)(\mu)}{(\pi)(r^4)}$$

This formula is often simplified for clinical applications to the following:

$$\Delta P = \dot{V}(R)$$

$$\dot{V} = \frac{\Delta P}{R}$$

ΔP = pressure gradient
$\dot{V}$ = volumetric flow rate
R = resistance

Simply stated, as the radius of a tube decreases by one-half, resistance increases sixteen times. As gas velocity increases, resistance to gas flow also increases. Increasing the length of a tube also will increase resistance to flow. These relationships will become very important when studying mechanical ventilation of the lungs. For example, if secretions within the airways increase, the effective radius of the airway decreases and resistance to gas flow increases dramatically. This will require higher pressures within the airway to maintain a constant flow.

For turbulent flow, the relationship between flow rate, pressure gradient, and the

radius of the tube is more complex. This is because the flow is affected by the shape of the tube, viscous forces that dissipate energy, and the Reynold's number. Generally, the volumetric flow rate is proportional to the radius to the 2.7th power, expressed as the following:

$$\dot{V} = r^{2.7}$$

The effect of radius on volumetric flow rate is not as great for turbulent flow as it is for laminar flow, but the effect is still quite pronounced. If the radius decreases by one-half, the volumetric flow rate is decreased by a factor of sixteen for laminar flow, and by a factor of between six and seven for turbulent flow. Generally, the flow of gas through most respiratory care equipment is turbulent rather than laminar. Laminar flow occurs physiologically within the lungs after several branches in the bronchial system.

GAS LAWS

An understanding of the gas laws is important in the practice of respiratory care. During mechanical ventilation, volumes, pressures, flows and the temperature of the gas delivered to a patient are routinely manipulated to better match changes in the patient's condition. It is important to be able to predict how these changes will affect gas delivery to the patient.

When performing mathematical calculations, it is important to use consistent units in all equations. For example, one can not mix cmH_2O and psi and expect correct results. It will be necessary to convert temperatures, and sometimes pressures, depending on the circumstances under which the gas laws are applied.

When converting temperature scales, you will need to apply the formulas listed in Table 1-2.

The two new temperature scales introduced are called the **absolute temperature** scales. Both scales are referenced to absolute zero. Therefore, neither scale will have negative numbers since the lowest temperature is zero.

Boyle's Law

Boyle's law relates the volume of a gas to its pressure. With temperature remaining constant, the volume of a gas varies inversely

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TABLE 1-2 Temperature Conversion

Degrees Fahrenheit to Degrees Celsius

$\dfrac{5}{9}$ (Fahrenheit Temperature − 32)
= Degrees Celsius

Degrees Celsius to Degrees Fahrenheit

$\dfrac{9}{5}$ (Celsius Temperature) + 32
= Degrees Fahrenheit

Degrees Celsius to Degrees Kelvin

Celsius Temperature + 273 = Degrees Kelvin

30 C + 273 = 303 K

Degrees Fahrenheit to Degrees Rankine

Fahrenheit Temperature + 460
= Degrees Rankine

70 F + 460 = 530 R

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with the pressure. Boyle's law is described in the following formula:

$$P_1(V_1) = P_2(V_2)$$

P_1 = original pressure
V_1 = original volume
P_2 = new pressure
V_2 = new volume

This formula is commonly rearranged as follows to solve for the original pressure (P_1) or the new pressure (P_2).

$$P_1 = \frac{P_2(V_2)}{V_1}$$

$$P_2 = \frac{P_1(V_1)}{V_2}$$

For example:

Given the following, V_1 = 500 ml, P_1 = 700 mmHg and P_2 = 300 mmHg, find the new volume.

$$\frac{P_1(V_1)}{V_2} = V_2$$

$$\frac{700 \text{ mmHg}(500 \text{ mL})}{300 \text{ mmHg}} = 1{,}167 \text{ mL}$$

This law is often applied in the mechanics of ventilation of the lungs and calculating residual volume using a body plethysmograph.

Charles' Law

Charles' law states that if pressure remains constant, the volume of a gas varies directly with the temperature (in degrees Kelvin). As the temperature increases, the volume of the gas also will increase. As the temperature of the gas decreases, volume will decrease. Charles' law is summarized in the following formula:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Before beginning this calculation, the temperature must first be converted to Kelvin, or absolute, temperature. To convert from Celsius to Kelvin, add 273 degrees. For example, given an original volume of 400 mL, an original temperature of 20 degrees Celsius and a new temperature of 40 degrees Celsius, find the new volume.

$$V_2 = \frac{T_2(V_1)}{T_1}$$

Converting Celsius to Kelvin:

$$20° + 273° = 293 \text{ K}$$
$$40° + 273° = 313 \text{ K}$$

$$V_2 = \frac{313°K(400 \text{ mL})}{293°K}$$

$$= 427.3 \text{ mL}$$

An easy way to demonstrate this law is to attach an inflated balloon to a small narrow-necked chemistry flask, then heat the flask with a Bunsen burner. As the gas warms, it expands, causing the balloon to become larger.

Dalton's Law

Dalton's law is sometimes referred to as the law of partial pressures. Dalton described how the pressure of a gas composed of a mixture of gases is equal to the sum of the partial pressures of all the discrete gases. That is, the total is equal to the sum of the parts. Furthermore, he stated that the partial pressure each gas exerts would be the same as if the gas occupied the total volume alone. Lastly, the partial pressure of each gas is proportional to its volumetric percentage.

For example:

Gas mixture D is composed of 15 mmHg gas A, 25 mmHg gas B and 200 mmHg gas C. What is the total pressure?

Gas A =		15 mmHg
Gas B =		25 mmHg
Gas C =	+	200 mmHg
Total Pressure =		240 mmHg

What is the percentage of each gas in the mixture?

Gas A percentage
    = 15 mmHg/240 mmHg = 6.3%

Gas B percentage
    = 25 mmHg/240 mmHg = 10.4%

Gas C percentage
    = 200 mmHg/240 mmHg = 83.3%

Another example of this law's use is the calculation of the partial pressures of the various gases in the atmosphere. Air is composed of nitrogen, oxygen, argon, and other gases sometimes referred to as trace gases.

Nitrogen	78.08%
Oxygen	20.95%
Argon	.93%
Carbon Dioxide	.03%
Trace Gases	.01%

At an atmospheric pressure of 640 mmHg (Denver, Colorado), what is the partial pressure of oxygen and how does that compare to the partial pressure of oxygen in Seattle, Washington (atmospheric pressure of 760 mmHg)?

Denver, Colorado:
640 mmHg × .2095 = 134.08 mmHg

Seattle, Washington:
760 mmHg × .2095 = 159.22 mmHg

There is a partial pressure difference of 25.14 mmHg for oxygen between the two cities due to a difference in atmospheric pressure.

Gay-Lussac's Law

Gay-Lussac described the relationship between pressure and temperature of a gas. He found that as temperature increases pressure will increase as long as volume is constant. This is known as **Gay-Lussac's law**. This relationship is described in the following formula:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

For example:

A gas at 30° C and 700 mmHg is compressed to 900 mmHg. What is the new temperature?

$$\frac{P_2(T_1)}{P_1} = T_2$$

$$30°C + 273 = 303 \text{ K}$$

$$\frac{900 \text{ mmHg}(303 \text{ K})}{700 \text{ mmHg}} = 389.6 \text{ K}$$

$$389.6 \text{ K} - 273° = 117.6°C$$

This law can be illustrated when a bicycle tire is inflated using a manual tire pump. As the air is compressed in the pump, its temperature increases. After the tire is inflated, the tire pump is noticeably warmer. In respiratory care equipment, air compressors have external fins that conduct and dissipate the heat generated when the ambient air is compressed.

Combined Gas Law

The **combined gas law**, or general gas law, is a combination of Boyle's, Charles' and Gay-Lussac's laws. It is useful in determining pressure, volume or temperature changes. The law is summarized in the following formula:

$$\frac{P_1(V_1)}{T_1} = \frac{P_2(V_2)}{T_2}$$

For example:

A gas at a pressure of 200 mmHg, 300° K, and occupying 6 liters has its temperature increased to 400° K while occupying the same volume. Find the new pressure.

$$\frac{P_1(V_1)(T_2)}{T_1(V_2)} = P_2$$

$$\frac{200 \text{ mmHg}(6 \text{ liters})(400 \text{ K})}{300 \text{ K}(6 \text{ liters})} = 389.6 \text{ K}$$

GAS DIFFUSION

Besides pressure, volume and temperature relationships, it is important to understand gas diffusion. Gas diffusion is important physiologically in that gases constantly move from the atmosphere into our bodies, and then from our cells into our blood, by means of diffusion. There are three important laws of gas diffusion: Fick's, Henry's and Graham's laws.

Fick's Law

Fick's law describes how a gas diffuses into another gas. Fick's law states that the rate of diffusion of a gas into another gas is proportional to its concentration. That is, as the concentration gradient between the gases increases, the rate of diffusion will increase. Given two gases, where Gas A has a higher concentration than Gas B, Gas A will diffuse more rapidly than Gas B due to its greater concentration.

Henry's Law

Henry's law describes how gases diffuse into and out of liquids. Henry's law states that the rate of a gas's diffusion into a liquid is proportional to the partial pressure of that gas at a given temperature. Applying Henry's law, observe what happens when you open a bottle of soda pop. Once the cap is removed, bubbles can be seen moving toward the surface of the liquid and bursting once they reach the surface. The partial pressure of carbon dioxide is greater in the liquid than in the atmosphere. Therefore, carbon dioxide gas diffuses from the dissolved state (liquid) to a gaseous state and escapes into the atmosphere.

Graham's Law

Gas diffusion in the blood is more complex than what occurs as described in Henry's law. Other factors, such as the gram molecular weight and solubility of the gases, must be accounted for when understanding diffusion across the alveolar capillary membrane.

Graham's law states that the rate of gas diffusion through a liquid is proportional to the solubility of a gas and inversely proportional to the gram molecular weight. Comparing oxygen and carbon dioxide, oxygen's solubility is .023, while carbon dioxide's solubility is .510.

$$\text{Solubility of } CO_2 = \frac{0.510}{0.023}$$

$$= \frac{22}{1}$$

This relationship shows that carbon dioxide is over 20 times more soluble in the blood than oxygen. Once the gases are dissolved, they must diffuse through the blood. In determining the rate of diffusion, you must now account for the gram molecular weight.

$$\text{Solubility} = \frac{(\text{Sol Coef CO}_2)(\sqrt{\text{gmw O}_2})}{(\text{Sol Coef O}_2)(\sqrt{\text{gmw CO}_2})}$$

$$= \frac{(0.510)(\sqrt{32})}{(0.023)(\sqrt{44})}$$

$$= \frac{19}{1}$$

This relationship shows that carbon dioxide is 19 times more diffusible in the blood than oxygen. This relationship is true, assuming that the partial pressures for the two gases are equal. Normally in the alveolus, the partial pressure of oxygen is greater than that for carbon dioxide, resulting in a slightly greater rate of diffusion for oxygen.

MEDICAL GAS SUPPLY EQUIPMENT

COMPRESSORS

Medical **compressors** provide oil-free compressed air to power equipment and also to mix with pure oxygen to provide lower oxygen concentrations. The compressed air must be oil free for two primary reasons: (1) oil particles, when inhaled, are not healthy, (2) oil droplets, when mixed with oxygen, may result in spontaneous combustion. (Spontaneous combustion is the ignition of a substance without the addition of heat.) There are three types of compressors: piston, diaphragm and centrifugal.

Piston Compressor

A piston compressor utilizes a piston driven by an electric motor (Figure 1-12). Carbon or Teflon® piston rings seal the piston against the cylinder wall, eliminating the need for oil. The compressed air is fed into a storage reservoir providing a large supply of air to meet high flow demands. A filter at the outlet removes any particles from the compressed air. The pressure is then reduced to 50 psi by means of a reducing valve before the air is fed into a piping system.

Diaphragm Compressor

Diaphragm compressors utilize a flexible diaphragm driven by an electric motor to compress the air. Diaphragm compressors are typically employed to power small nebulizers. They are not capable of providing the large amounts of compressed air needed for large
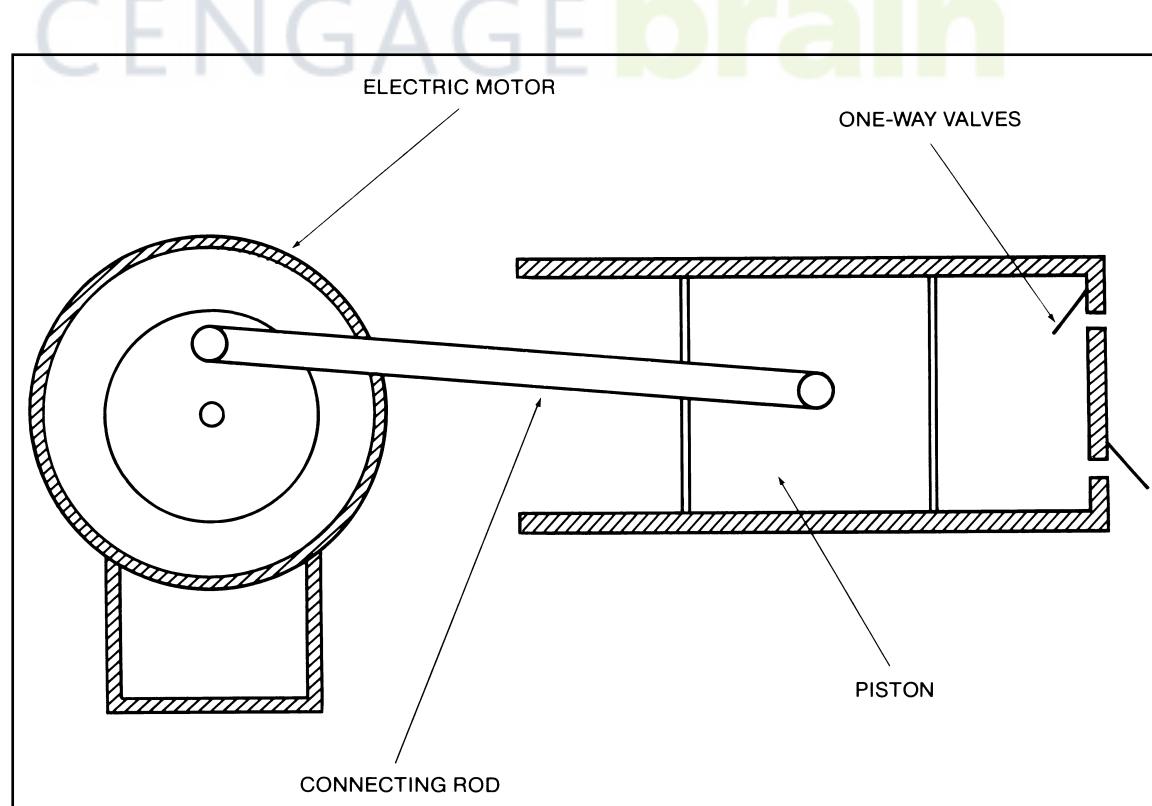
Figure 1-12 *A functional diagram of a piston compressor.*

ASSEMBLY AND TROUBLESHOOTING

Assembly—Compressors

To prepare a compressor for use, complete the following steps.

1. Connect the power cord to the correct electrical outlet—115 volts, alternating current (VAC).

2. Attach equipment requiring compressed air to the threaded outlet.

3. Check inlet filter for obstruction and, if required, clean or replace it.

4. Turn on the compressor with the on/off switch.

5. Verify correct outlet pressure (50 psi) with the gauge provided.

Troubleshooting

Troubleshooting compressors is very easy. Unfortunately, if the unit fails to operate, little can be done other than to take the compressor to an authorized repair center. When troubleshooting this equipment, please follow the suggested troubleshooting algorithm (ALG 1-1).

equipment. Figure 1-13 depicts a typical diaphragm compressor suitable for home use.

Centrifugal Compressor

The **centrifugal compressor** utilizes an electrically powered impeller mounted eccentrically within the compressor housing. As the impeller rotates, it compresses the air. Centrifugal force and the decreasing size of

the chamber compress the gas as the impeller turns (Figure 1-14). These compressors are incorporated in some adult mechanical ventilators such as the Bennett MA-1.

A larger version of this type of compressor is used to provide a compressed air source for hospitals and other institutions. These rotary compressors use similar principles of operation, except that a working fluid (usually water) is used between the impeller and the
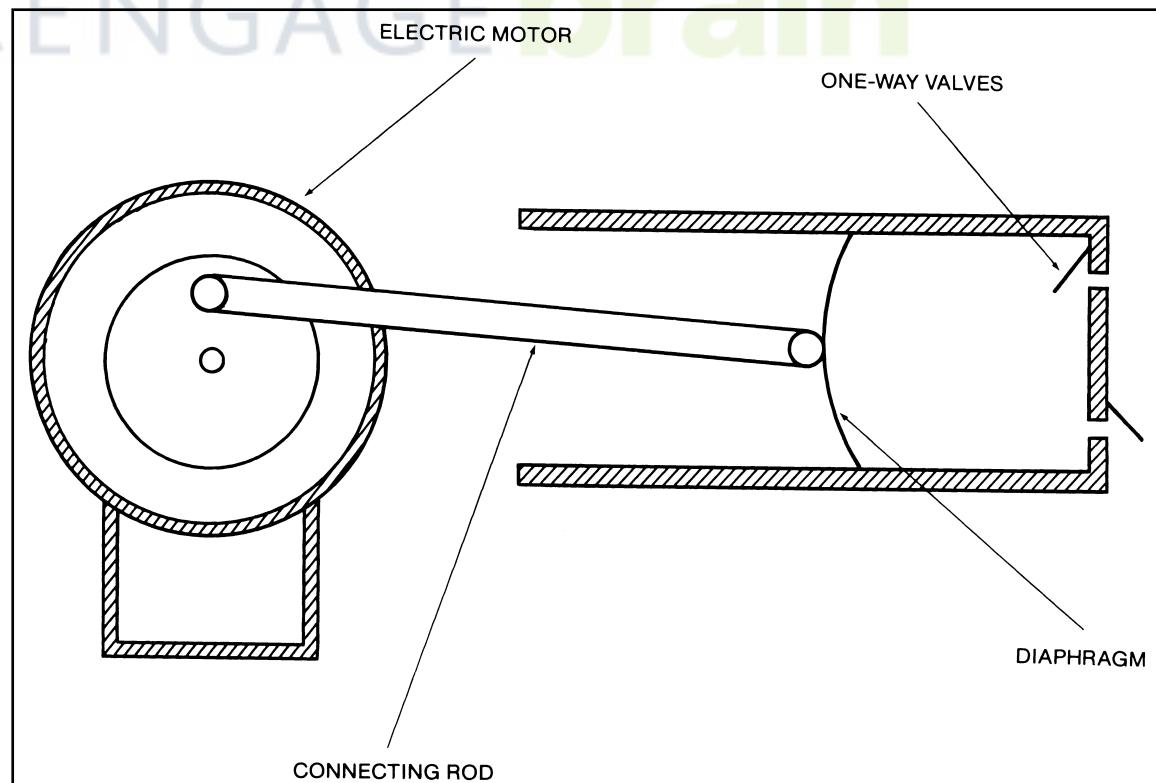
Figure 1-13 *A functional diagram of a diaphragm compressor.*
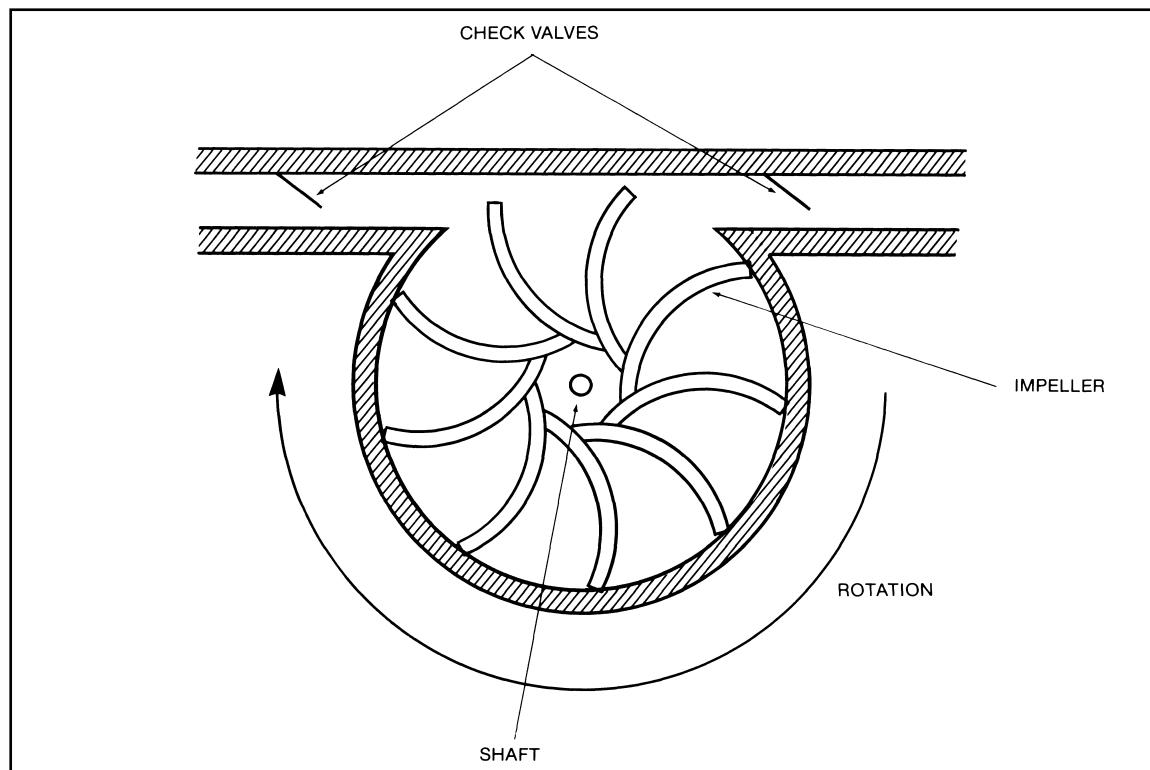
Figure 1-14   *A functional diagram of a centrifugal compressor.*

compressor housing. The working fluid allows tolerances to be greater between the impeller and the compressor housing, reducing wear and eliminating the need for lubrication. A water separator and particle filters purify the air prior to delivery to the hospital piping system.

Water traps should be used with all ventilators powered by compressed gases. Water can become condensed as air or oxygen is pressurized. A contemporary ventilator's pneumatic, electronic control and monitoring system can be damaged by water that may be contained in the high pressure supply lines. To avoid this potential problem, the use of water traps is recommended by most manufacturers.

CONCENTRATORS

Oxygen concentrators are electrically powered devices that separate the oxygen from the atmosphere and deliver it under pressure for medical use. There are two types of oxygen concentrating devices, molecular sieve and membrane types.

The **molecular sieve concentrator** is more effective than the membrane type. Inlet air to a compressor is passed through a particle filter to remove large particles from the air. Then the gas is passed through a bacteria filter that removes particles as small as 0.3 microns. The filtered air is then compressed by a compressor to approximately 20 psi, and conducted to molecular sieves containing Zeolite. The compressed gas alternately charges one sieve and then the other. The Zeolite in the sieve adsorbs some of the nitrogen and passes the oxygen contained in the ambient air, thus increasing the oxygen concentration.

The process of **adsorption** is a surface phenomenon in which the gas molecules are forced under pressure into the pores of the Zeolite. As the nitrogen oxygen mixture (air) flows through the pores of the Zeolite, the nitrogen molecules stick or adhere to the surface and the oxygen molecules pass through. When the sieve is depressurized, the nitrogen is released to the atmosphere and exhausted, separating it from the oxygen-enriched gas.

Oxygen concentrators use some of the oxygen-rich gas flowing from one sieve to purge the other sieve. This is done prior to pressurization to improve oxygen percentage levels. The purge cycle helps to rid the canister of nitrogen before it is again pressurized with room air.

Oxygen concentration will vary between 50% to greater than 90% depending on the
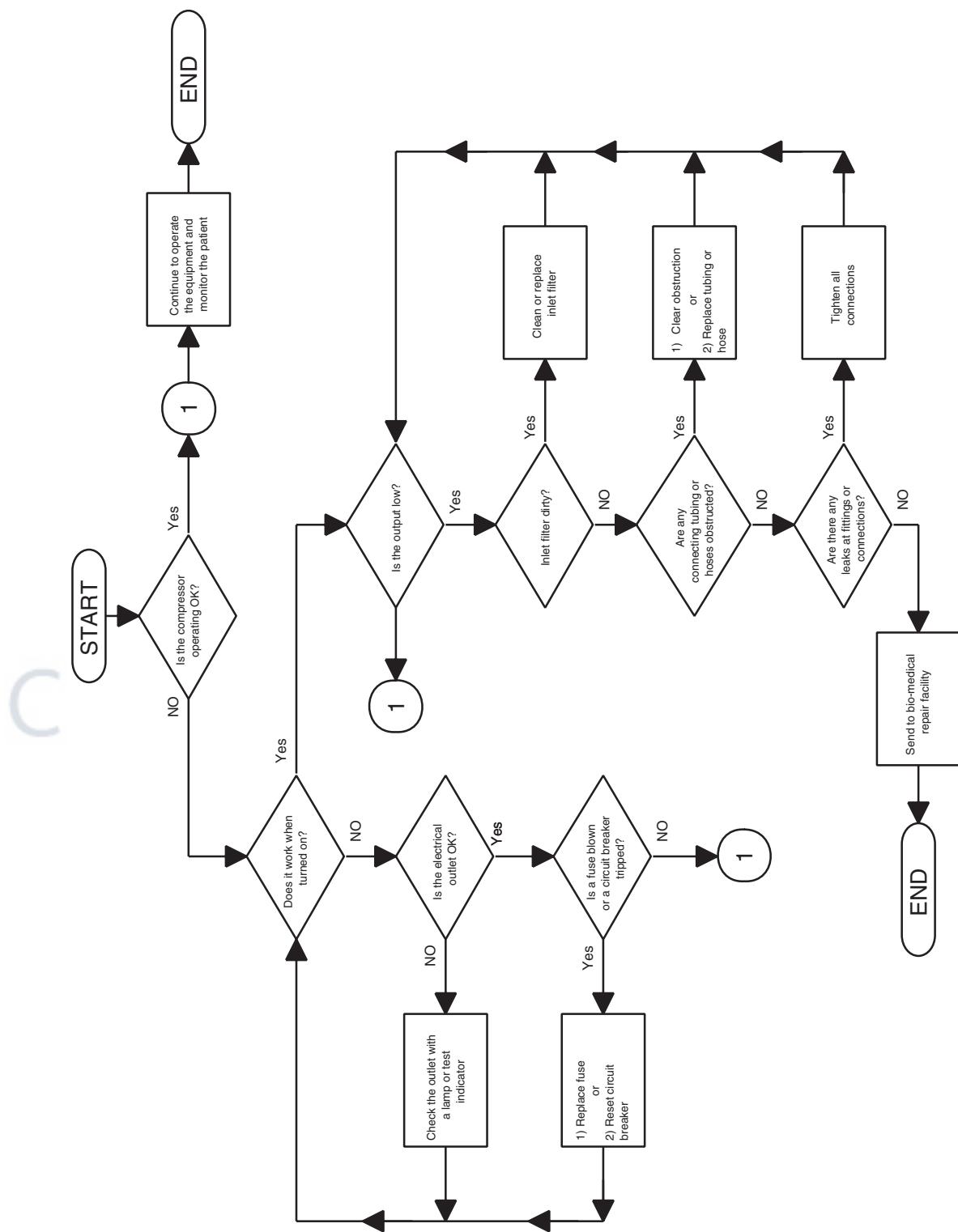
ALG 1-1 *An algorithm describing how to troubleshoot a compressor.*
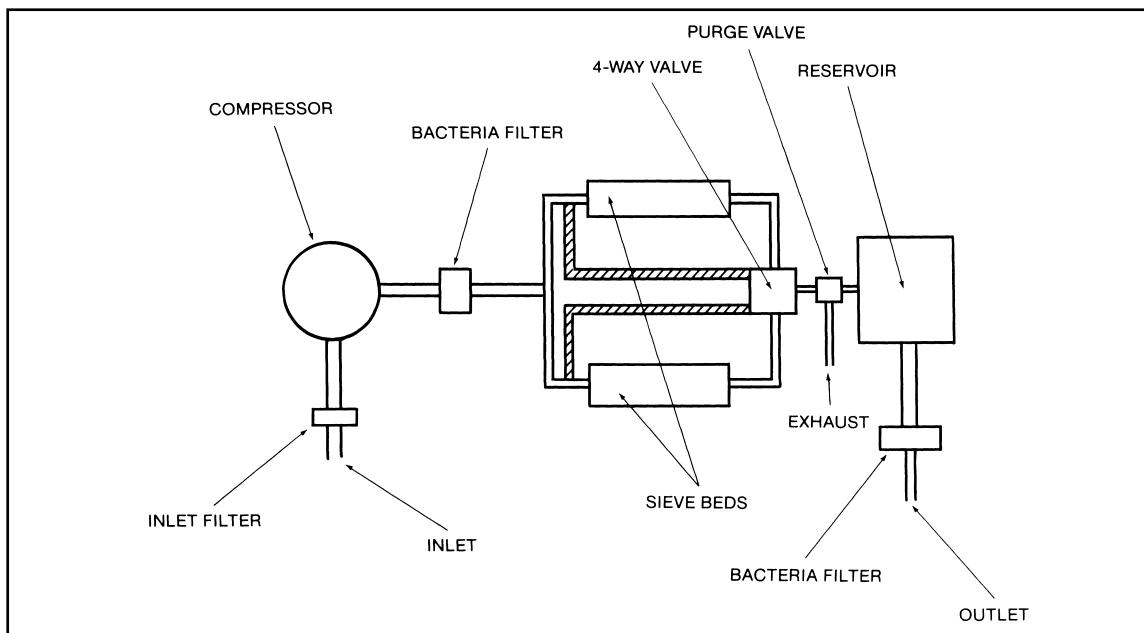
Figure 1-15   *A functional diagram of an oxygen concentrator.*

flow rate out of the concentrator. If the flow rate is set for 2 liters (L) per minute or less, the oxygen concentration will be 90% or sometimes higher. If flow is increased to 10 liters per minute, the oxygen concentration drops to 50%. Figure 1-15 shows a schematic of a typical oxygen concentrator and its component parts.

The **membrane enricher**, commonly called an enricher, uses a semipermeable polymer membrane to remove the nitrogen from the air. An air compressor forces the air through the one-micron-thick membrane, allowing the smaller oxygen molecules to pass. A membrane enricher can provide a concentration of 40% oxygen at flow rates between 1 and 10 liters per minute.

Invacare® Platinum™ 5 Oxygen Concentrator

The Invacare® Platinum™ 5 oxygen concentrator is a unit that uses molecular sieve technology to separate oxygen from room air (Figure 1-16).

The unit is capable of providing low-flow oxygen at concentrations between 95.6% to 87% from flows between 0.5 to 5 L/min. These concentrators allow patients to receive continuous oxygen without the use of liquid oxygen systems or compressed gas cylinders. Power consumption averages 400 watts during continuous operation.

Figure 1-16   *A photograph of the Invacare® Platinum™ 5 oxygen concentrator.*

Invacare® Venture® HomeFill™ II Oxygen Filling System

Invacare® Venture® HomeFill™ II oxygen filling system is a small multistage compressor that is designed to interface with the Invacare® 5-liter oxygen concentrators (Figure 1-17). The oxygen filling system allows patients to transfill small ambulatory cylinders from the oxygen concentrator's output. The unit is

Figure 1-17 *A photograph of the Invacare® Venture® HomeFill™ II oxygen filling system. This unit is a multi-stage pump designed to fill portable oxygen cylinders.*

designed to interface with the Invacare® ML6 (164 liter) and M9 (248 liter) capacity portable oxygen cylinders. It takes approximately 1½ to 2½ hours to fill a cylinder (ML6 and M9, respectively). The filling system provides patient independence from their home care provider delivering filled portable oxygen cylinders for ambulatory use, as well as long-term cost savings.

Liter flow from the concentrator during transfilling is limited to 0 to 3 L/min. The input to the transfilling compressor during operation is 2 L/min. Power consumption averages 200 watts when transfilling the cylinders. An electrical outlet separate from the concentrator must be available for the Home-Fill II® oxygen filling system, in that each unit has its own independent power supply.

Puritan Bennett Companion 492a

The Puritan Bennett Companion 492a oxygen concentrator operates using two molecu-

Figure 1-18 *A photograph of the Puritan Bennett Companion 492a oxygen concentrator. (Courtesy Puritan Bennett Corporation, Lenexa, KS)*

lar sieves to separate oxygen from room air (Figure 1-18). The unit is capable of providing 95% oxygen concentration ± 3% at flows between 1 and 3 L/min. If the oxygen flow is 4 L/min, oxygen concentrations are 92% ± 3%. During normal operation the Companion 492a will consume an average of 330 watts electrical power. Ideally, the concentrator should be the only item connected to the electrical outlet and on that electrical circuit.

ASSEMBLY AND TROUBLESHOOTING

Oxygen Concentrators

1. Position the oxygen concentrator in the room where your patient will spend the majority of his or her time. Be sure to choose a location away from heaters, radiators, and hot-air registers. Place the unit so that the back and sides are at least 6 inches away from any objects to ensure adequate air flow through the unit.

2. Concentrators incorporate a particle filter. Remove the filter from its housing or holder. Inspect the particle filter for lint or other debris. The patient should be instructed to wash this filter at least once a week. The filter may be washed in a solution of warm water and dishwashing detergent and then rinsed thoroughly with warm tap water and toweled dry. The filter should be

completely dry before it is reinstalled. The particle filter may also be cleaned daily by using a vacuum cleaner attachment without removing the filter from the concentrator. The filter must still be washed weekly.

3. If humidification has been prescribed:
   a. Fill the humidifier reservoir with distilled water to the "fill" line and then thread the humidifier directly onto the fixed oxygen Diameter Index Safety System (DISS) outlet so that the humidifier is suspended.
   b. Attach the desired length of oxygen delivery tubing (not to exceed 50 feet, or 15 meters) to the humidifier outlet. If condensation occurs when using longer lengths of oxygen tubing, condensation may be reduced by using a removable humidifier stand.

4. If humidification has not been prescribed:
   a. Thread a green "Christmas Tree" fitting onto the fixed oxygen DISS outlet fitting and attach the desired length of oxygen delivery tubing (not to exceed 50 feet, or 15 meters).

5. Connect the cannula, transtracheal cannula, or mask to the oxygen delivery tubing.

6. Check to be certain that the power switch is in the "OFF" position. Select an electrical outlet (120 V, 60 Hz) that is not connected by a wall switch and is independent of other appliances.

7. Depress the power switch to the "ON" position.

8. Adjust the flowmeter to the prescribed oxygen setting by turning the flowmeter knob counterclockwise to increase the flow of oxygen. Verify oxygen flow through the cannula/delivery tubing and or the humidifier. An oxygen analyzer can be used to confirm that the concentration being delivered is correct.

Troubleshooting

Follow the suggested troubleshooting algorithm (ALG 1-2) to assist you in troubleshooting this concentrator.

1. If the unit fails to operate when turned on:
   a. Check to be certain that the power cord is plugged into a 120 V, 60 Hz electrical outlet.
   b. The electrical outlet may not have power. Test the outlet with a household lamp or radio. If the power is not on at the outlet, use another outlet.
   c. The circuit breaker has tripped. Press the black reset button on the rear cover. If the breaker trips again, contact your dealer for service.

2. If the air intake or exhaust is blocked:
   a. Check and service the gross particle filter if required.
   b. Check for objects blocking discharge air from the bottom right side of the unit.

3. If the unit is operating but you are unable to obtain the desired flow of enriched gas, check the following:
   a. Blocked oxygen delivery device or connecting tubing.
      (1) Remove the delivery device (cannula, catheter, or transtracheal catheter) from the extension tubing. If flow is restored, clean or replace the delivery device.
      (2) Disconnect the extension tubing from the humidifier. If flow is restored, check the tubing for kinks or obstructions, or replace the tubing as required.
   b. Blocked or defective humidifier.
      (1) Remove the humidifier from the outlet of the MC84. If flow is restored, clean or replace the humidifier.
   c. Use of excessive length of connecting tubing. Use a maximum of 50 feet, or 15 meters, of tubing.

4. If the unit operates but you are unable to obtain the appropriate oxygen concentration:
   a. Ensure the patient has an adequate supply of compressed oxygen or liquid oxygen.
   b. Remove the unit from service and return it to an authorized service center.
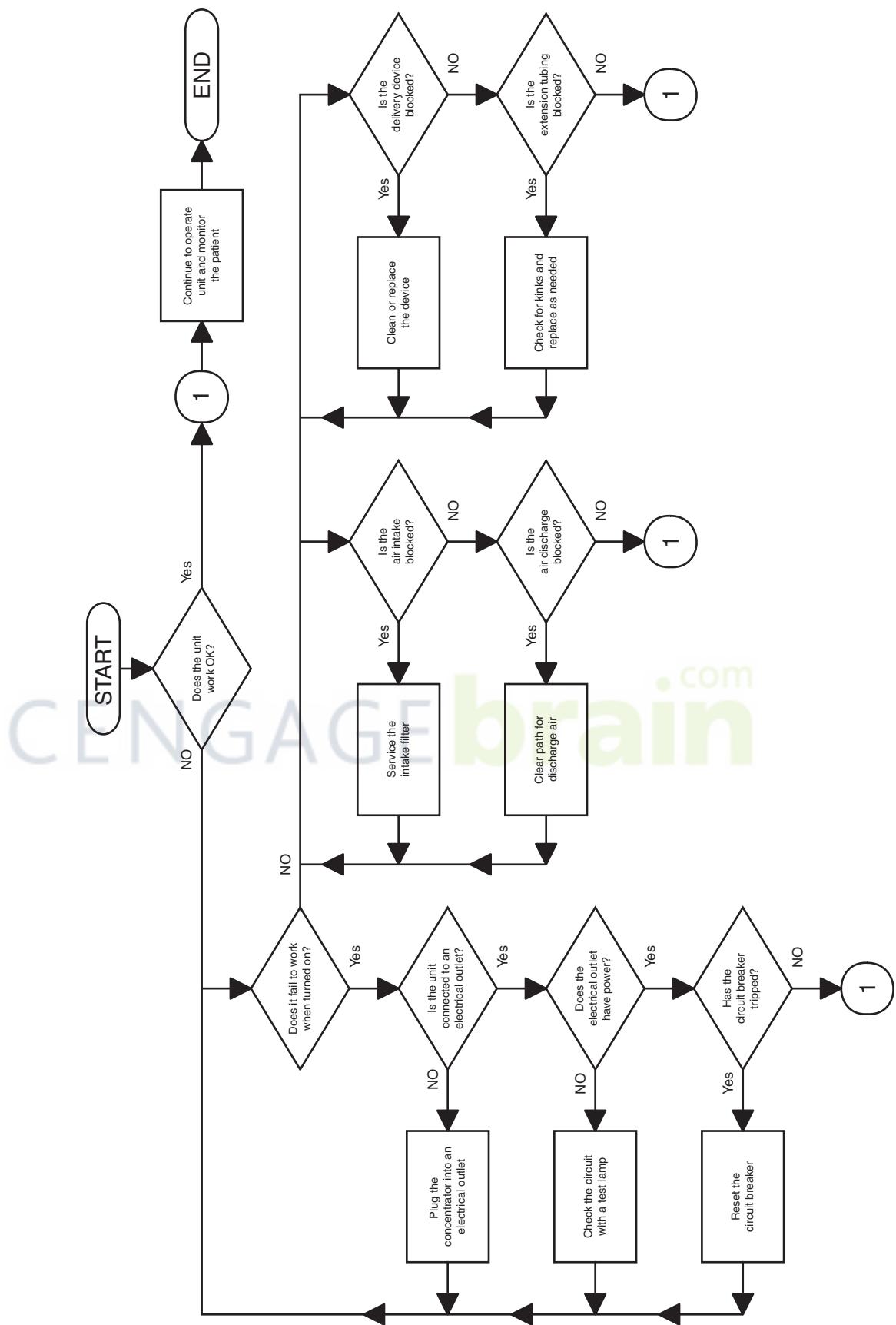
ALG 1-2 *An algorithm describing how to troubleshoot oxygen concentrators.*

LIQUID RESERVOIR SYSTEMS

Bulk Supply Systems

Bulk supply systems are used to supply large amounts of medical gas to a hospital or other institution. It is more economical to operate a bulk system than to use many small cylinders. The construction of a bulk liquid storage reservoir is very similar to an enlarged steel thermos. An outer steel shell encloses several layers of insulation in a near vacuum. The inner wall contains the liquid gas (Figure 1-19). Standards of bulk reservoir construction have been established by the American Society of Mechanical Engineers. Liquid oxygen is stored in the reservoir at a temperature of –183° Celsius. Liquid oxygen continuously vaporizes, creating pressure. Pressure relief valves are incorporated into the reservoir to release pressure. The release of pressure, as the gas expands, cools the reservoir (Gay-Lussac's law).

It is important to size the reservoir properly, so that the use of gas exceeds the rate of vaporization. If too much gas is lost to the atmosphere by vaporization, it may not be economical to operate the bulk system. An advantage of storing oxygen in liquid form is that one cubic foot of liquid oxygen expands to 861 heat exchanger cubic feet of gaseous oxygen (1:861 ratio). The liquid oxygen is fed

into a heat exchanger like a radiator; it warms the liquid to a gas (Figure 1-19). Once the liquid has vaporized to a gas, pressure will have increased. The pressure is reduced to 50 psi by passing through a reducing valve. After the pressure has been reduced to 50 psi, the gas is then fed into the piping system.

Portable Reservoirs

Smaller liquid reservoirs have been designed for home and ambulatory use (Figure 1-20). The principles of construction are similar to the large bulk systems described earlier, only smaller in scale.

The larger reservoirs designed for stationary use in the home vary in capacity from 20 to 43 liquid liters. Although the capacity may seem small, remember that one liquid liter of oxygen is equal to 861 gaseous liters. This makes the capacity in gaseous liters range from 16,400 to 35,200 liters. Physical size ranges of these reservoirs are diameters of 12–15 inches and heights of 27–38 inches and weights that vary, when full, between 84 and 160 lbs.

The smaller portable reservoirs are designed to be easily carried on the shoulder or placed into a small cart for ambulation. The liquid capacities of these portable units range from .6 liters to 1.23 liters, giving them a gaseous capacity of 500 to 1058 liters. Weights
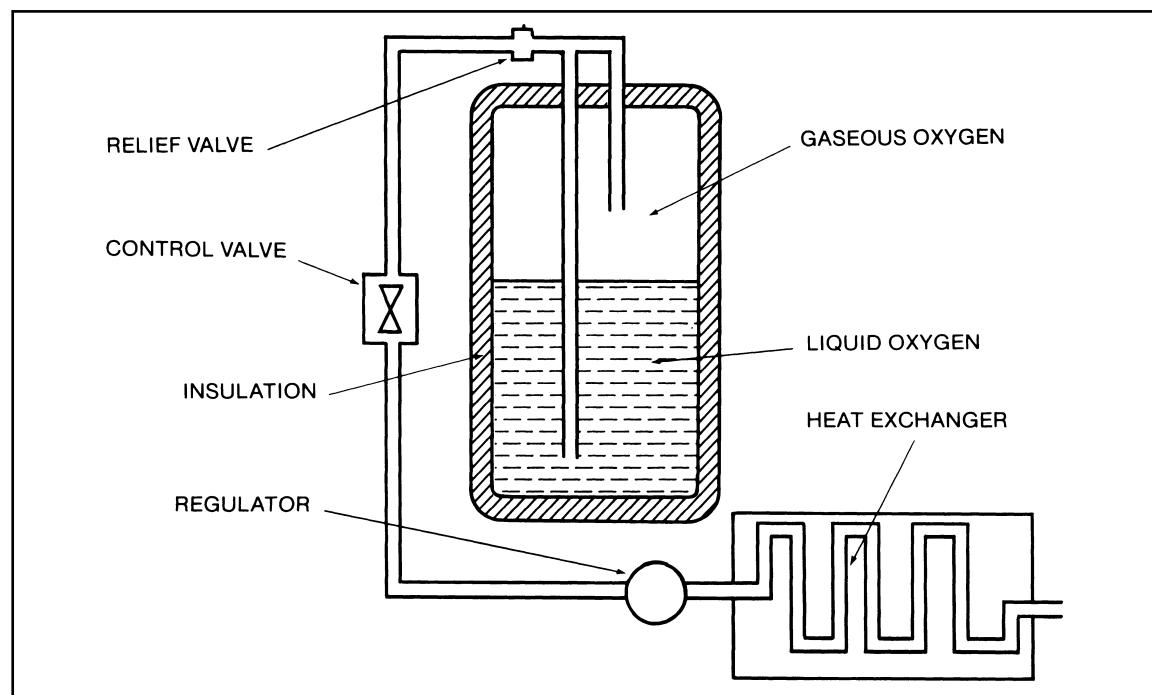
Figure 1-19 *A bulk liquid oxygen storage and supply system. Note the insulated container, control valve, and heat exchanger. The heat exchanger converts the liquid to a gas by warming it.*

Figure 1-20 *A contemporary portable liquid home oxygen system. The larger reservoir is for use in the home. The smaller portable reservoir may be filled from the larger one for trips away from home lasting up to eight hours at flow rates less than 2 liters per minute. (Courtesy CAIRE, Inc., Bloomington, MN)*

Figure 1-21 *A photograph of the HELiOS® portable oxygen system.*

of these units when full vary from 5.3 to 9.0 lbs. Oxygen conservation devices such as pulse demand flow regulators (described later in this chapter), when used in conjunction with the liquid reservoirs, can dramatically extend the duration of oxygen supply. These devices, when coupled with liquid supply systems and cylinders, can result in oxygen savings of 3–7 times when compared to conventional continuous oxygen flow delivery.

Mallinckrodt Puritan Bennett® HELiOS® Portable Liquid Oxygen System

The HELiOS® portable oxygen system is a small lightweight liquid oxygen reservoir that incorporates a pneumatic oxygen conserving device (Figure 1-21). Patients requiring continuous oxygen may be independent and ambulatory with this unit for up to 8 to 10 hours at a setting of 2 on the conserving device. The weight of the unit when full is 3.6 pounds and only 2.7 pounds when empty. The unit must be used with the dual lumen nasal cannula

that allows the pneumatic system to sense the patient's inspiration, delivering oxygen during the inspiratory phase of ventilation. The rate of oxygen evaporative loss from the unit is between 1 to 1.5 pounds per day. The portable unit can be filled from a larger liquid reservoir in less than one minute (40 seconds).

Portable Oxygen Duration

It may be necessary to calculate the duration of oxygen flow from these portable liquid reservoirs. These calculations are all based upon the weight of the units. All portable systems incorporate some form of spring scale to estimate the contents remaining. Many are calibrated in fourths and some use LED displays to further subdivide the contents into smaller increments. However, these scales are only estimates and do not accurately reflect the contents remaining in the reservoirs.

Sometimes it may be necessary to accurately calculate the number of liters or duration in time remaining in a portable liquid system. These calculations are also based upon weight. However, since the accuracy of spring scales varies, all calculations shown incorporate a scale factor (.80) to allow for variation in scales. It is also required that you know the

empty weight of the reservoir you are working with. This can be found in the owner's manual or service manual.

Derivation of the formula:

(1) Density of O_2 at its boiling point
   $= 1141 \text{ kg/m}^3$

(2) $1141.0 \text{ kg/m}^3 \ (2.2 \text{ lb/kg}) = 2510.2 \text{ lb/m}^3$

(3) $2510.2 \text{ lbs/m}^3 \ (.001 \text{ m}^3/\text{L})$
   $= 2.5102 \text{ lbs/L}$

(4) 1 liter (liquid) $= 860.6$ liters (gaseous)

$$\frac{860.6 \text{ liters (gas)}}{2.5102 \text{ lbs/L (liquid)}} = \frac{324.8 \text{ L (gas)}}{\text{lbs (liquid)}}$$

RESULT: There are 342.8 L gaseous oxygen per lb of liquid oxygen.

For example:

You are working with a patient in her home who is using a large portable reservoir at 2 L/min. She wants to know how long her reservoir will last before it needs to be refilled.

The indicator says it is ½ full, but she is still concerned. What is the duration of the reservoir?

Empty Weight = 60 lbs (from service manual)

Current Weight = 145 lbs

Scale Factor = .80

$(145 \text{ lbs} - 60 \text{ lbs [liquid]}) = 342.8 \text{ L}$ (gas)/lb (liquid) $\times .80 = 23,310 \text{ L}$ (gas)

$$\frac{23,310 \text{ L (gas)}}{2 \text{ L min}} = 11,655 \text{ minutes}$$

$$\frac{11,655 \text{ minutes}}{60 \text{ minutes/hour}} = 194 \text{ hours, or 8 days}$$

Notice in the calculation that the capacity in liters was multiplied by .80. This scale factor gives you a reserve or cushion of 20% to allow for accuracy variation in the spring scale used to weigh the liquid reservoir.

ASSEMBLY AND TROUBLESHOOTING

Assembly—Portable Liquid Oxygen Systems

Little is required for proper assembly of portable liquid reservoirs. The following guide will help you in the assembly and preparation of the reservoir for use.

1. Ensure that the reservoir is filled by checking the weight gauge provided.
   a. Should the reservoir require filling, contact your local vendor.

2. Attach a flowmeter and humidifier to the threaded outlet of the reservoir.

3. Attach the oxygen therapy equipment to the outlet of the humidifier.

4. Turn on the flowmeter to the ordered setting and observe for proper flow. When transfilling the ambulatory reservoirs, follow the manufacturer's instructions carefully. Since connections and attachment vary, specific instructions are not included here. When transfilling the portable reservoir, exercise caution. The extreme cold

temperatures of the fittings may result in cryogenic burns!

Troubleshooting

When troubleshooting this equipment, please follow the suggested troubleshooting algorithm (ALG 1-3).

1. If gas fails to flow from the oxygen therapy device:
   a. Check to ensure the reservoir is full, using the weight gauge or other gauge provided by the manufacturer.
   b. Check all connections for tightness. Check for leaks by feeling and by listening for escaping gas.
   c. Make certain that the humidifier is assembled correctly and that it is not obstructed. Check to ensure that all threaded connections are tight.
   d. Check oxygen tubing for kinks or obstruction.
   e. If (a) through (d) are satisfactory, contact your local vendor.
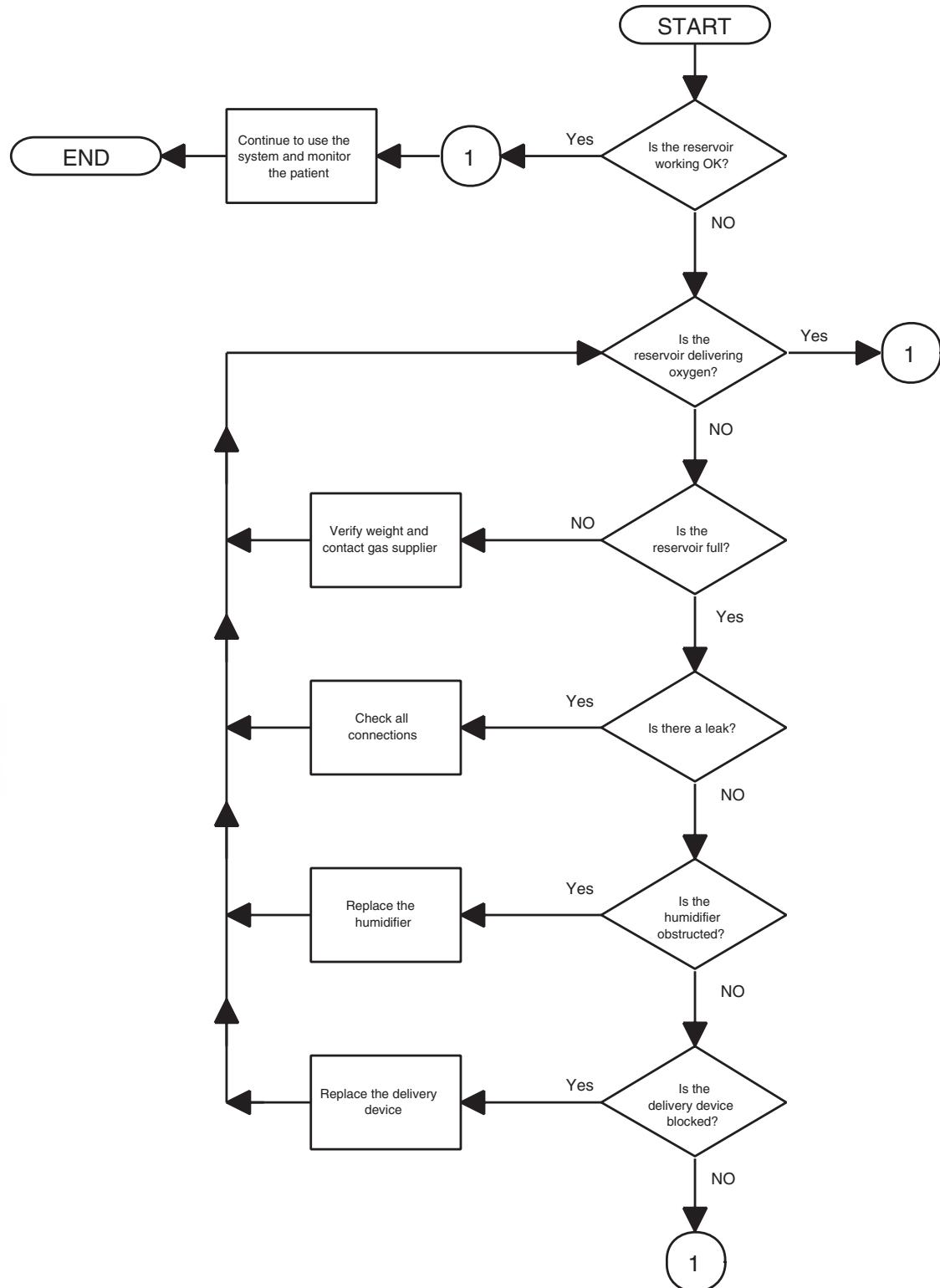
ALG 1-3 *An algorithm describing how to troubleshoot a portable liquid oxygen reservoir.*

PIPING SYSTEMS

Piping systems provide a safe, convenient way to distribute medical gases throughout an institution. The initial cost of these systems is quite high; however, over time they may be more cost effective than cylinders, depending on the quantity of medical gases used.

CONSTRUCTION OF PIPING SYSTEMS

The National Fire Protection Association has established standards for the construction and operation of medical gas piping systems.

Supply

Oxygen may be supplied from a **manifold** of two or more cylinders, a bulk liquid reservoir or both. A manifold consists of two or more cylinders connected together using high-pressure steel or copper tubing. When two or more cylinders are interconnected, the total volume of gas available is greater than a single cylinder alone. Part C of Figure 1-22 depicts a schematic of an oxygen supply system using two cylinder manifolds. Figure 1-22 illustrates the three primary types of supply systems. The supply system is designed to meet the

Figure 1-22 *Bulk oxygen supply systems that are typical for most medical care facilities. (A) Liquid primary and liquid reserve, (B) Liquid primary and cylinder reserve, and (C) Cylinder primary and cylinder reserve.*

institution's needs, and requires periodic filling from an oxygen vendor. Liquid gas can be delivered whenever the reservoir requires filling, or on a regularly scheduled basis. It is transported to the institution by truck or by rail.

A reserve supply is required to provide up to 24 hours of oxygen in the event that the main supply becomes depleted. The reserve supply can consist of a smaller liquid reservoir or a manifold of cylinders. When pressure in the main supply drops, a valve automatically opens, activating the reserve supply.

The pressure is reduced by means of a regulator or reducing valve before the gas enters the piping system.

Piping System Construction

A piping system conducts the gas through copper pipes to points of use. This piping system is similar in design to the water system in your home or apartment; however, it must conform to stricter standards of construction. These systems are made from seamless K- or L-type copper tubing. The tubing must meet specific standards regarding its ability to withstand pressure without rupturing. All joints are sweat soldered using silver solder.

Sweat soldering is accomplished by applying heat to the joint using a torch. The solder is melted, flows into the joint, and seals it. Flux may be used to clean the joint and allow the solder to adhere to the metal better.

After soldering, joints are carefully checked for leaks. The pipes are independently supported to the building structure at specified intervals. This means that nothing else may be attached to the building's structure at the same point where the medical gas piping system is attached. Following construction, the system is cleaned of any flux or debris and pressure tested. The system is pressurized to 1.5 times its working pressure with dry, oil-free air or with nitrogen. Each joint is then checked for leaks. The system is allowed to stand for 24 hours at this pressure and must remain leak free during this time in order to pass final inspection.

Following the pressure test, both the oxygen and air supply lines are charged with gas. The oxygen piping system is supplied by a bulk oxygen system, while a medical air compressor supplies gas for the air piping system. The outlets are then tested for purity. Oxygen and air lines are checked with analyzers to ensure that they are delivering the correct gas.
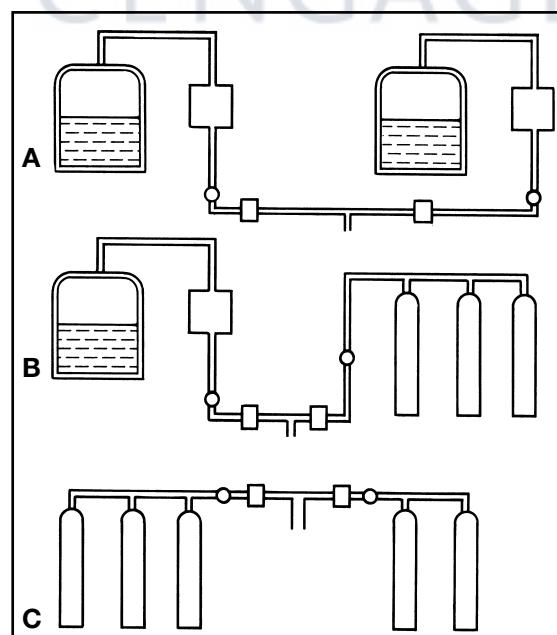
Once the purity test has been completed, the system may be used for patient care.

Safety Features

Safety features in a medical gas piping system include alarms, zone valves, riser valves and pressure sensors.

Alarms are included in a piping system. These alert personnel to pressure drops in the system caused by leaks or depletion of the gas supply. The alarm must be placed in an area that is attended 24 hours a day. For this reason, the hospital telephone switchboard is a common location for medical gas alarm panels.

Zone valves are shutoff valves placed at strategic positions so that gas supply to different areas may be cut off in the event of a fire. Zone valves also are placed at the base of risers (pipes conducting gas from one floor to another), as shown in Figure 1-23. In some acute care facilities, Respiratory Care Practitioners (RCPs), are required to identify and turn off the appropriate zone valves in the

event of a fire. If a zone valve is turned off, the RCP is also responsible to ensure that patients requiring oxygen receive it from cylinders or another source during transport from the scene of a fire and also when returning the patients to their rooms.

Pressure sensors are placed throughout the piping system to monitor pressure. Line pressure in most hospital systems is 50 psi.

Station Outlets

Medical gas outlets, located at the points of desired use, are termed station outlets. Special fittings are incorporated into these outlets, preventing the connection of equipment designed for a different gas. Examples of these fittings include Diameter Indexed Safety Fittings and quick-connect fittings.

The Diameter Indexed Safety System (DISS) was designed by the Compressed Gas Association. This system utilizes differing thread pitch, connection diameter, and internal and external threading to prevent the
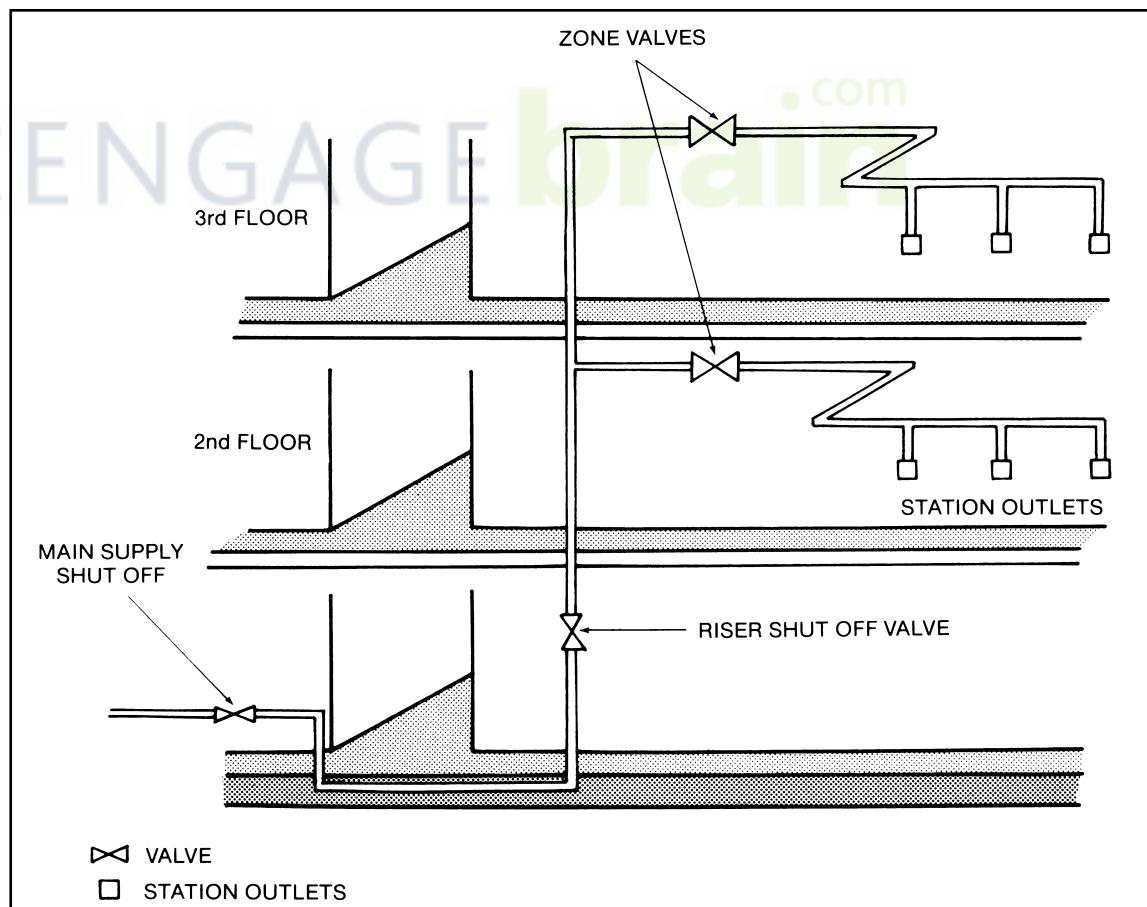
Figure 1-23 *Placement of safety shutoff valves in a piping system. Note the placement of the main supply shutoff, riser valves, and zone valves.*

Figure 1-26 *A photograph of a carbon fiber-wrapped cylinder developed for ambulatory patient use.*

"DOT" refers to the Department of Transportation and "3AA" indicates heat treated high strength steel. The designation "3AL" denotes aluminum construction. Typically, cylinders are filled to a pressure 10% greater than the working pressure indicated on its shoulder, providing the cylinder has passed the required hydrostatic testing.

Light weight aluminum cylinders reinforced with carbon fiber wrap have been developed for ambulatory patient use (Figure 1-26). These cylinders incorporate an ultra-thin aluminum wall reinforced with helical and hoop wraps of carbon fiber impregnated with epoxy resin for reinforcement. The weight savings over steel cylinders of similar size is approximately 70%, and about a 30% weight savings is realized compared with con-

ventional aluminum cylinder construction. The cylinders are designed to be filled to a service pressure of 3000 psi. When used with oxygen-conserving devices, these cylinders can provide a long duration with a very light-weight package for ambulatory use.

Cylinder Markings

The DOT requires that cylinder data be stamped on the shoulder of the cylinder (Figures 1-27 and 1-28).

Hydrostatic Testing

Every five years a cylinder is subjected to a hydrostatic test to measure its elasticity. The cylinder is filled to a pressure equal to 5/3 its working pressure and cylinder expansion is measured. If the expansion is within tolerance, the cylinder is returned to service. If the cylinder fails the test, it is removed from service and destroyed. The inspector's mark and the date of the test, followed by a "+" sign (steel cylinders only), are then stamped into the shoulder of the cylinder. If a star follows the inspection date, the cylinder may go for ten years before another hydrostatic test is performed (steel cylinders only).

Some communities may be limited in their ability to provide hydrostatic testing for fiber-wrapped cylinders since the designed service pressure is 3000 psi. The testing site would need equipment capable of exceeding 5000 psi pressure to hydrostatically test a fiber-wrapped cylinder.

Figure 1-27 *Cylinder markings indicate the cylinder has passed inspection. The inspection was performed in March 1982. The inspector's mark is between the month and year. The "+" sign indicates the cylinder complies with the hydrostatic test. The star marking indicates the cylinder may go ten years before being tested again.*
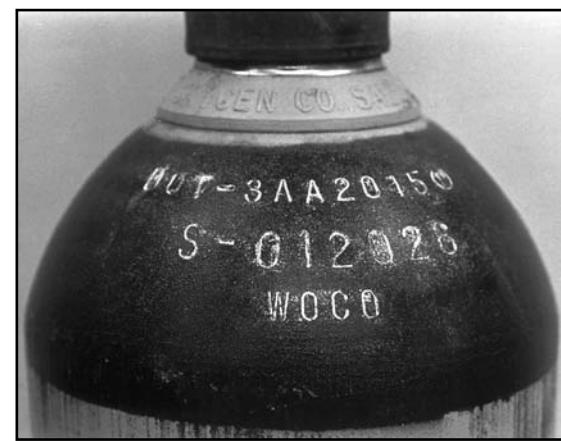
Figure 1-28 *Cylinder markings indicate that the cylinder is made from high tensile strength heat-treated steel (DOT 3AA) and has a service pressure of 2015 psi (2015). The serial number is below the DOT numbers and the owner's stamp is below the serial number.*

Cylinder Sizes

Medical gas cylinders are manufactured in many sizes (Figure 1-29). The most common sizes encountered in the hospital environment are the "H" and the "E" cylinders. The "H" cylinder contains 244 cubic feet of oxygen and weighs approximately 135 pounds. The "E" cylinder contains 22 cubic feet of oxygen and weighs approximately 16 pounds. Since the "E" cylinder is smaller and lighter, it is usually used for ambulation of patients (with a cart) and for transporting patients from one place to another within the hospital.

Color Coding

The Compressed Gas Association has developed a color code for the different medical gases and gas mixtures. This code was published by the Department of Commerce through the recommendation of the Bureau of Standards. An international color code also exists for medical gases. The only difference between the two color codes is the color for

COMMON METRIC EQUIVALENTS (APPROX.)
1 Cubic Foot....7.48 gallons....28.3 liters
1 Gallon.........3.785 liters....... 0.132 cubic feet
1 Liter...........0.264 gallons.... 0.035 cubic feet

|		B/BB	D/DD	E	M	G	H
CO_2	Liters	370	940	1590	7570	12300	15800
	Gals.	100	250	420	2000	3263	4180
	C.F.	13.37	33.2	56.1	267	436	558
	Wt.	1 lb., 8 oz.	3 lbs., 13 oz.	6 lbs., 7 oz.	30 lbs., 10 oz.	50 lbs., 0 oz.	64 lbs., 0 oz.
CO_2 / O_2	Liters		400	660	3000	5330	6000
	Gals.		105	174	793	1408	1585
	C.F.		14.1	23.3	106	188	212
	Wt.		1 lb., 3 oz.	2 lbs., 0 oz.	8 lbs., 15 oz.	15 lbs., 14 oz.	17 lbs., 14 oz.
C_3H_6	Liters	378	871				
	Gals.	100	230				
	C.F.	13.37	30.75				
	Wt.	1 lb., 7.25 oz.	3 lb., 5.5 oz.				
He	Liters		300	500	2260	4000	6000
	Gals.		79.2	132	597	1057	1585
	C.F.		10.6	17.6	79.8	141	213
	Wt.		0 lbs., 1.8 oz.	0 lbs., 2.9 oz.	0 lbs., 13.2 oz.	1 lb., 7.5 oz.	2 lbs., 2.8 oz.
He / O_2	Liters			500	2260	4000	4500
	Gals.			132	597	1057	1189
	C.F.			17.6	79.8	141	159
	Wt.						
N_2O	Liters		940	1590	7570	13800	15800
	Gals.		249	420	2000	3657	4200
	C.F.		33.2	56.1	267	489	558
	Wt.		3 lbs., 13 oz.	6 lbs., 7 oz.	30 lbs., 10 oz.	56 lbs., 0 oz.	64 lbs., 0 oz.
O_2	Liters	200	400	660	3450	5300	6900
	Gals.	52.8	105	174	912	1400	1825
	C.F.	7	14.1	23.3	122	187	244
	Wt.	9.4 oz.	1 lb., 3 oz.	1 lb., 15 oz.	10 lbs., 1 oz.	15 lbs., 8 oz.	20 lbs., 3 oz.
Air	Liters		375	625	3275	5050	6550
	Gals.		99	165	865	1334	1730
	C.F.		13.2	22	116	178	232
	Wt.		1 lb., 0 oz.	1 lb., 10 oz.	8 lbs., 11 oz.	13 lbs., 5 oz.	17 lbs., 6 oz.
N_2	Liters			610			6400
	Gals.			161			1676
	C.F.			21.5			224
	Wt.			1 lb., 9 oz.			16 lbs., 6 oz.

Figure 1-29 *Cylinders are manufactured in different sizes. (Courtesy BOC Gases, formerly Airco, Murray Hill, NJ)*

TABLE 1-3 Cylinder Color Coding

Gas	Color Code	
	United States	**International**
Oxygen	Green	White
Carbon dioxide	Gray	Gray
Nitrous oxide	Light blue	Light blue
Cyclopropane	Orange	Orange
Helium	Brown	Brown
Carbon dioxide and oxygen	Gray and green	Gray and white
Helium and oxygen	Brown and green	Brown and white
Air	Yellow	White and black

cylinders containing oxygen (see Table 1-3). The international color is white, while the United States still uses green. In addition to the color code, each cylinder is required to have a label indicating the cylinder's contents.

Labeling of cylinder contents is required by the United States Pharmacopeia (USP), a division of the Food and Drug Administration (FDA). The USP controls the purity standards of compressed gases for medical use.

If the label and the color code do not match, the cylinder should not be used and should be returned to the vendor. The most reliable indicator of what is contained in the cylinder is the label.

SAFETY RULES FOR CYLINDER USE

Common sense and the practice of certain safety precautions will ensure safety for both you and your patient. Remember at all times that a medical gas cylinder contains gas pressurized up to 2200 psi. If the cylinder or cylinder valve were to rupture, disastrous consequences could result. Rules and precautions, recommended by the Compressed Gas Association and published in their pamphlet "Characteristics and Safe Handling of Medical Gases, 1971," are summarized in Table 1-4.

TABLE 1-4 Safety Rules for Cylinder Use

Moving Cylinders
1. Always leave protective valve caps in place when moving a cylinder.
2. Do not lift a cylinder by its cap.
3. Do not drop a cylinder, strike two cylinders against one another, or strike other surfaces.
4. Do not drag or slide cylinders; use a cart.
5. Use a cart whenever loading or unloading cylinders.

Storing Cylinders
1. Comply with local and state regulations for cylinder storage as well as with those established by the National Fire Protection Association.
2. Post the names of gases stored.
3. Keep full and empty cylinders separate. Place the full cylinders in a convenient spot to minimize handling of cylinders.
4. Keep storage areas dry, cool, and well ventilated. Storage rooms should be fire-resistant.
5. Do not store cylinders close to flammable substances such as gasoline, grease, or petroleum products.

(continues)

TABLE 1-4 *(continued)*

6. Protect the cylinders from being damaged by cuts or abrasions. Do not store them in areas where they may be damaged by moving or falling objects. Keep cylinder valve caps on at all times.

7. Cylinders may be stored in the open; however, keep them on a platform so they are above the ground.In some parts of the country, shading may be required due to high temperatures. If ice and snow accumulate, thaw at room temperature or use water cooler than 125° F.

8. Protect cylinders from potential tampering by untrained, unauthorized individuals.

Withdrawing Cylinder Contents

1. Allow cylinders to be handled by experienced, trained individuals only.

2. The user of the cylinder is responsible for verifying the cylinder contents before use. If the contents are in doubt, do not use the cylinder. Return it to the supplier.

3. Leave the protective valve cap in place until you are ready to attach a regulator or other equipment.

4. Follow safety precautions. Make sure the cylinder is well supported and protected from falling over.

5. Always crack the cylinder valve prior to attaching a regulator or reducing valve. (Refer to previous "Assembly and Troubleshooting" section.)

6. Use appropriate reducing valves or regulators when attaching equipment designed for lower operating pressures than those contained in the cylinder.

7. Do not force any threaded connections.Verify that the threads you are using are designed for the same gas or gas mixture in accordance with the American Standard Safety System.

8. Connect a cylinder to a manifold designed for high pressure cylinders only.

9. Use equipment only with cylinders containing the gases for which the equipment was designed.

10. Open cylinder valves slowly. Never use a wrench or hammer to force a cylinder valve open. Treat cylinders and cylinder valves with care.

11. Do not use compressed gases to dust off yourself or your clothing.

12. Keep all connections tight to prevent leakage.

13. Before removing a regulator, turn off the valve and bleed the pressure.

14. Never use a flame to detect leaks with flammable gases.

15. Do not store flammable gases with oxygen. Keep all flammable anesthetic gases stored in a separate area.

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DURATION OF GAS FLOW

In order to calculate how long a cylinder will last at a given liter flow, it is important to remember four key facts:

1. When full, an "H" cylinder contains 244 cubic feet of oxygen.

2. When full, an "E" cylinder contains 22 cubic feet of oxygen.

3. Full cylinders contain 2200 psi pressure.

4. One cubic foot of oxygen equals 28.3 liters.

Once these facts have been committed to memory, the duration of any "H" or "E" cylinder may be calculated.

Tank Factors

It is common practice to use tank factors in the calculation of cylinder duration. By knowing the four key facts listed above, these factors may be derived. Table 1-5 illustrates how these factors are derived.

Once these factors have been derived, it is

TABLE 1-5 Tank Factor Calculation

$$\text{Tank Factor} = \frac{\text{Size (cu ft.)} \times 28.3 \text{ liters/cu ft}}{\text{Pressure when full}}$$

$$\text{"H" cylinder} = \frac{244 \text{ cu ft} (28.3 \text{ liters/cu ft})}{2200 \text{ psi}}$$

$$= 3.14 \text{ liters/psi}$$

$$\text{"E" cylinder} = \frac{22 \text{ cu ft} (28.3 \text{ liters/cu ft})}{2200 \text{ psi}}$$

$$= .28 \text{ liters/psi}$$

easy to convert from gauge pressure (psi) directly to liters. To accomplish this, multiply the gauge pressure by the tank factor for that cylinder. For example:

You are asked to help move a patient from the Emergency Room to the Intensive Care Unit, which usually takes about twenty minutes. You are manually ventilating the patient using a resuscitation bag at a liter flow of 15 liters per minute. Will the department's "E" cylinder containing 1000 psi have enough gas for the transport?

Step 1:
"E" tank factor

$$= \frac{22 \text{ cu ft} (28.3 \text{ liters/cu ft}}{2200 \text{ psi}}$$

$$= 0.28 \text{ liters/psi}$$

Step 2:
Content of cylinder

$$= \text{tank factor} \times \text{gauge pressure}$$
$$= .28 \text{ liters/psi} \times 1000 \text{ psi}$$
$$= 280 \text{ liters}$$

Step 3:
Duration in minutes

$$= \frac{\text{cylinder contents}}{\text{liter flow}}$$

$$= \frac{280 \text{ L}}{15 \text{ L/min}}$$

$$= 18 \text{ minutes}$$

Answer: No, the cylinder will not last!

Note: It is common to arrive at an answer of hours expressed as a decimal form—for example, 6.3 hours. Each tenth of an hour is 6 minutes, so 6.3 hours equals 6 hours and 18 minutes.

It is common clinical practice to leave 500 psi remaining in the cylinder prior to changing it, providing that a maximum duration is not desired (airborne or ground transport). By leaving 500 psi in the cylinder, water, other gases and foreign material cannot enter the cylinder, helping to extend its useful life.

To calculate the cylinder duration, leaving 500 psi in a cylinder, follow the example outlined below.

You are asked to set a patient up on an oxygen mask at 12 L/min in the X-ray department. The facility is in an older part of the institution and does not have piped oxygen. You move an "H" cylinder to the area to supply oxygen for your patient. The cylinder gauge reads 1250 psi. How long will the cylinder last if you leave 500 psi remaining in the cylinder?

Step 1:
"H" tank factor

$$= \frac{244 \text{ cu ft} (28.3 \text{ liter/cu ft})}{2200 \text{ psi}}$$

$$= 3.14 \text{ L/psi}$$

Step 2:
Content of cylinder

$$= \text{tank factor} \times (\text{gauge pressure} - 500 \text{ psi})$$
$$= .28 \text{ L/psi} (1250 \text{ psi} - 500 \text{ psi})$$
$$= 2355 \text{ L}$$

Step 3:
Duration in minutes

$$= \frac{\text{cylinder contents}}{\text{liter flow}}$$

$$= \frac{2355 \text{ L}}{12 \text{ L/min}}$$

$$= 196 \text{ minutes}$$

$$= 3 \text{ hours } 12 \text{ minutes}$$

This type of problem and others like it are very common in clinical practice. Your patient's safety may depend on your ability to remember how to perform these simple calculations.

ASSEMBLY AND TROUBLESHOOTING

Assembly—Oxygen Cylinders

To prepare a cylinder for use, complete the following instructions.

1. Transport the cylinder to the point of use by employing a cylinder cart. Be sure that the protective valve cap is in place when transporting the cylinder.

2. Position the cylinder upright and attach it using chains provided at the point of use, or use a cylinder stand to prevent it from tipping over.

3. Remove the protective cap ("H" cylinder). The smaller "E" cylinders have a piece of shrink-wrap plastic tape protecting the cylinder valve and outlet. Remove the protective tape prior to attaching a regulator or reducing valve.

4. Announce to personnel or patients in the area that a loud noise will occur.

5. Position the cylinder such that the cylinder valve opening is pointing away from any people in the room. "Crack" the cylinder by quickly opening and closing the valve to eliminate debris from the cylinder valve opening.

6. Attach an appropriate regulator to the cylinder and attach the oxygen therapy equipment to the regulator.

7. Slowly turn on the cylinder valve.

8. Read the pressure gauge and determine if the contents of the cylinder are adequate for the duration of therapy.

Troubleshooting

Troubleshooting a cylinder is quite simple since this oxygen supply system has so few moving parts. The following is a suggested troubleshooting algorithm (ALG 1-4).

1. Check for leaks at the connection between the cylinder and regulator. If leaks are present, tighten the connection.
   a. A leak can be detected by a hissing sound. The amplitude or volume of the sound indicates the severity of the leak.
   b. Subtle leaks may be detected by feeling for gas flow with your hands around the connections.
   c. If you suspect a leak but can't detect it:
      (1) Use a solution of mild detergent and water, and brush the solution around the fittings. Leaks will cause bubbles to form, indicating the presence of a leak.
   d. If a leak is detected, turn off the cylinder valve (bleeding all pressure from the regulator) and retighten all connections.

2. Check for leaks between the regulator and the oxygen therapy equipment and tighten as appropriate.
   a. A leak can be detected by a hissing sound. The amplitude or volume of the sound indicates the severity of the leak.
   b. Subtle leaks may be detected by feeling for gas flow with your hands around the connections.
   c. If you suspect a leak but can't detect it:
      (1) Use a solution of mild detergent and water, and brush the solution around the fittings. Leaks will cause bubbles to form, indicating the presence of a leak.
   d. If a leak is detected, turn off the cylinder valve (bleeding all pressure from the regulator) and retighten all connections.

3. If gas fails to flow from the cylinder, check the pressure gauge to ensure that the cylinder has pressure.
   a. If the cylinder contains pressure, check the regulator outlet for obstructions.
   b. If the above is satisfied, replace the regulator with another and try again.
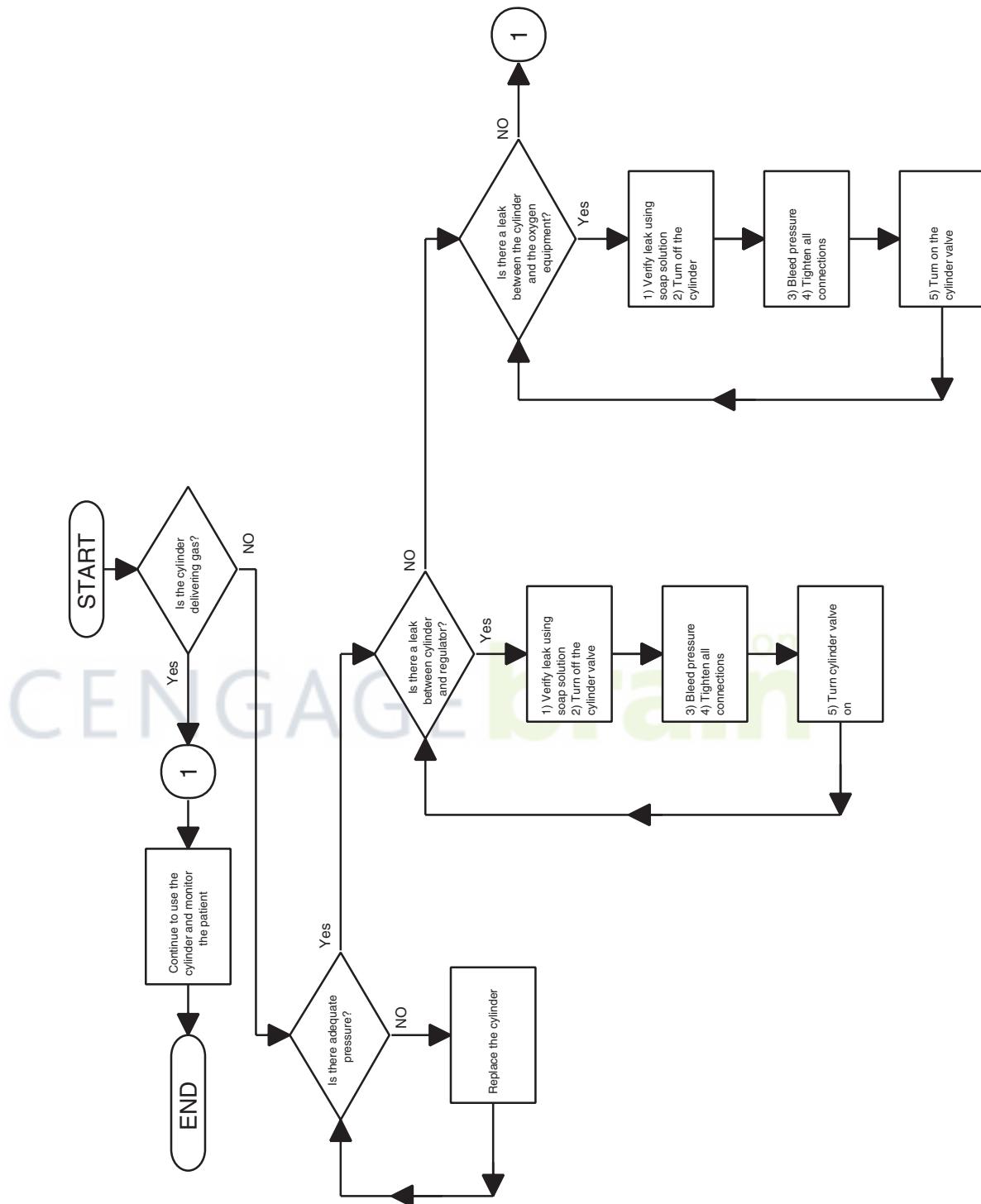
ALG 1-4 *An algorithm describing how to troubleshoot medical gas cylinders.*

OXYGEN REGULATION DEVICES

Cylinders that contain highly pressurized gas would be dangerous to use without specialized equipment to regulate gas flow and allow safe attachment of other equipment. It is important to understand the operation of cylinder valves and reducing valves to safely use cylinders.

Direct Acting Cylinder Valve

As its name implies, the **direct acting cylinder valve** operates by opening and closing the valve seat directly. As the valve stem or wheel is turned, the valve plunger moves up or down, acting directly on the valve seat. As the valve seat is opened, gas moves from the area of high pressure (within the cylinder) to the area of lower pressure (out of the cylinder). Figure 1-30 shows the component parts of the cylinder valve. The valve plunger is threaded, so as the stem is turned, it opens or

closes. The direct acting cylinder valve is a type of needle valve.

Diaphragm Cylinder Valve

In this type of cylinder valve, a diaphragm opens or closes the valve seat. As the valve stem is turned, the threaded plunger moves up or down, allowing the diaphragm to open or close the valve seat. Gas pressure then displaces the diaphragm, allowing gas to flow out of the cylinder. These valves are usually employed with cylinders having a lower working pressure of 1500 psi or less (Figure 1-31).

Cylinder Valve Safety Features

Several safety features are incorporated into cylinder valves.

Since cylinders contain many different gases, the Compressed Gas Association (CGA) has designed a system to prevent the interchange of dissimilar gases. In other words, the safety system is designed to prevent the attachment of an oxygen regulator to a nitrous oxide medical gas cylinder. The two types of valve outlet safety systems are the American Standard and the Pin Index Safety System (PISS).

The American Standard Safety System (ASSS) is incorporated into the valves for the larger cylinders (sizes "M," "G," "H"). This system uses differing thread pitches, internal
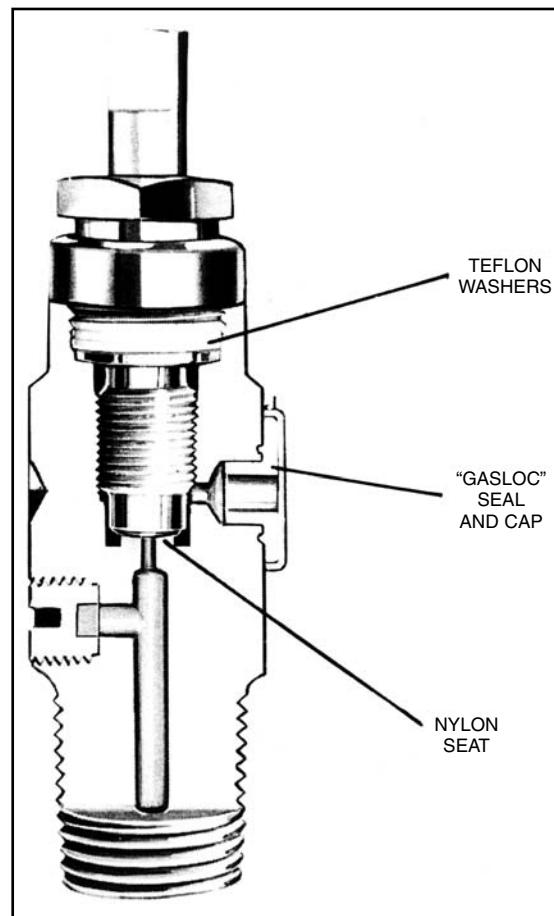
Figure 1-30 *A full section of a direct acting cylinder valve. (Courtesy BOC Gases, formerly Airco, Murray Hill, NJ)*
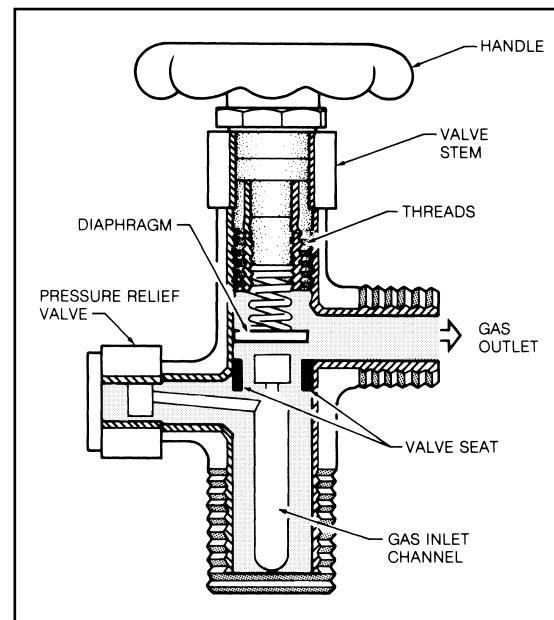
Figure 1-31 *A functional diagram of an indirect acting cylinder valve.*
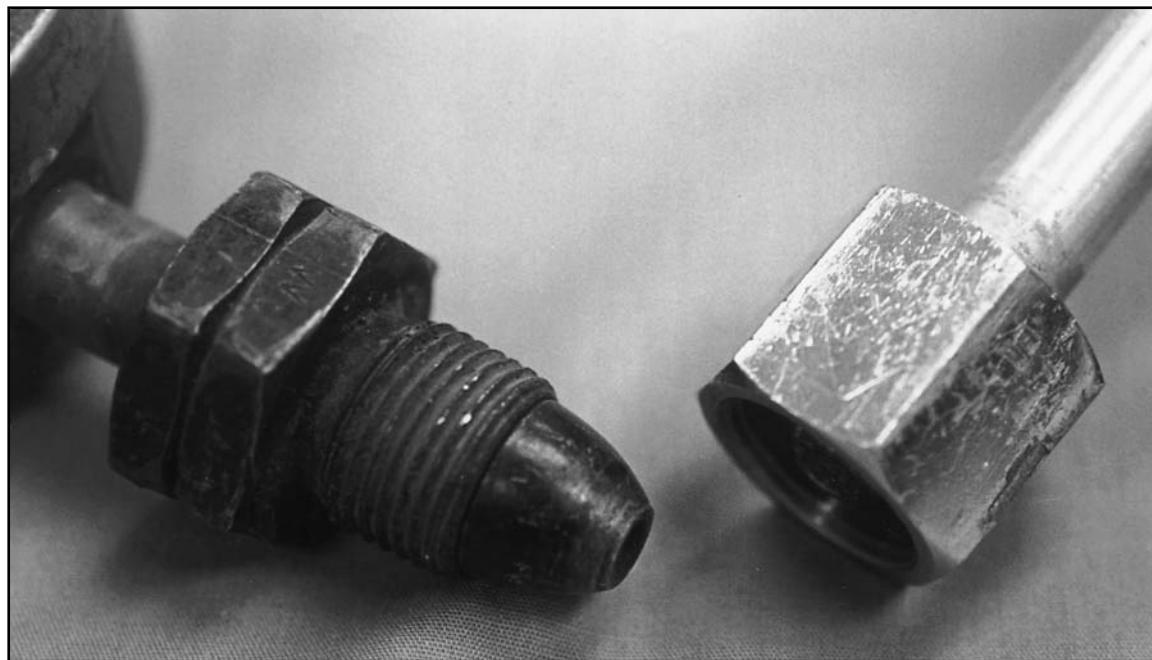
Figure 1-32 *Differing threads and pitches for cylinder valve connections. Note the threads on the left are external (acetylene), and the threads on the right are internal (oxygen).*

left- and right-hand threads, and external threading to prevent the attachment of equipment not designed for the gas contained in the cylinder. Figure 1-32 shows acetylene and oxygen American Standard fittings. Note how one is internally threaded and the other is externally threaded.

The smaller cylinder valves (sizes "AA"–"E") use a yoke type connection between the cylinder valve and the reducing valve. The Pin Index Safety System incorporates pins in the reducing valve yoke and holes on the cylinder valve at specified positions to prevent the attachment of equipment not designed for the gas contained in the cylinder. Figure 1-33 illustrates how this safety system works using the different pin positions.

In addition to the indexing safety systems, pressure release devices are built into the cylinder valves. These pressure relief devices will open if pressure or temperature rises beyond safe limits. The two types of pressure relief devices are the frangible disk and the fusible plug. These devices may be used singly or in combination with one another.

The frangible disk pressure relief consists of a thin metal disk that contains the pressure within the valve. If the pressure within the cylinder rises abnormally, the disk will burst or fracture, releasing pressure before the cylinder walls rupture.

The fusible plug pressure relief is made from an alloy that will melt when the ambient temperature exceeds 208–220° Fahrenheit. When the plug melts or distorts, pressure will be released, preventing rupture of the cylinder.

OXYGEN 2-5
AIR 1-5
He/O$_2$ (80% and under) 2-4
CO$_2$/O$_2$ (7% or under) 2-6
NITROUS OXIDE 3-5
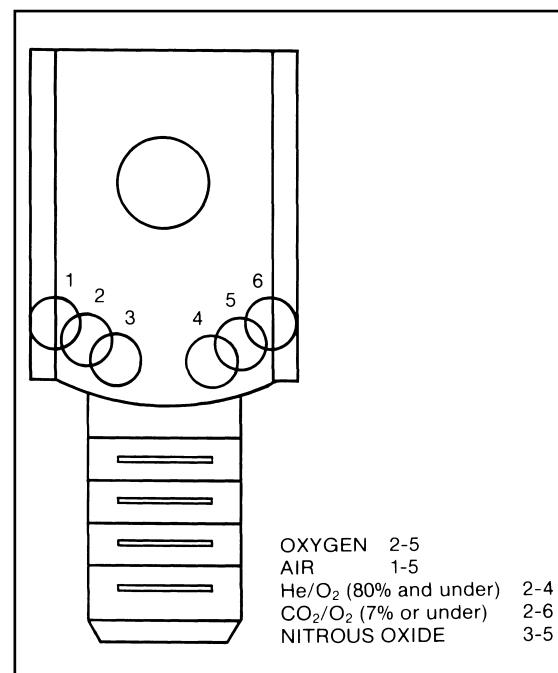
**Figure 1-33** *Pin index positions for medical gases.*

REDUCING VALVES

Single-Stage Reducing Valve

A single-stage **reducing valve** reduces the pressure from the cylinder to a working pressure in one step or stage. All reducing valves operate by using two opposing forces, spring tension and gas pressure separated by a flexible diaphragm. Figure 1-34 illustrates the component parts of a single-stage reducing valve and its operation. Gas pressure in the cylinder displaces the diaphragm upward. When gas pressure and spring tension are equal, the diaphragm is flat, closing the poppet valve. As the pressure within the chamber drops, spring tension forces the diaphragm down, opening the poppet valve. This cycle repeats itself with the diaphragm oscillating back and forth, opening and closing the poppet valve. Spring tension determines the outlet pressure from the reducing valve. The tension may be fixed or adjustable depending on the reducing valve's construction. If the tension is adjustable, there is usually a screw provided that will allow adjustment of the tension against the diaphragm.

Modified Single-Stage Reducing Valve

The modified single-stage reducing valve is similar to the single-stage reducing valve. The difference between the two is that the modified single stage reducing valve has a poppet closing spring in addition to the spring above the diaphragm. Figure 1-35 illustrates the component parts of this reducing valve. The poppet closing spring allows the poppet valve to open and close faster, providing greater flow rates.

Multistage Reducing Valves

Multistage reducing valves are simply two or more single-stage reducing valves in series with one another. Figure 1-36 shows the component parts of this reducing valve. The first stage reduces the cylinder to an intermediate pressure of approximately 200 psi. The second stage then reduces the pressure to the desired working pressure, usually 50 psi. Each stage operates independently from the other.

The addition of the additional stage allows more precise regulation of pressure and a greater flow rate than is possible with a single-stage reducing valve. Common applications of multistage reducing valves include powering of mechanical ventilators. These applications require high flows and a stable pressure source.

Reducing Valve Safety Features

Several safety features are incorporated into the design of reducing valves. These include pressure relief valves, or pop-off valves, and indexing of the inlet and outlet.

Each stage of a reducing valve is required to have a safety relief valve in the event that excess pressure develops within the stage. The safety relief will exhaust excessive pressure before the reducing valve housing bursts.

The inlet of the reducing valve is indexed with either American Standard indexing or the Pin Index Safety System indexing. Both of these systems were developed by the Compressed Gas Association and discussed earlier in this chapter.

The outlet of the reducing valve uses Diameter Indexed Safety System threads. This safety system was also discussed earlier in this chapter.

Figure 1-34 *Functional diagram of a single-stage reducing valve.*
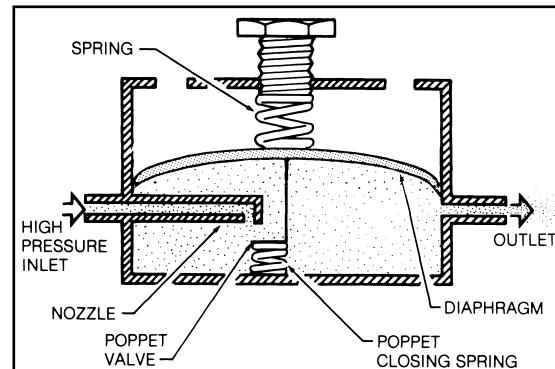
Figure 1-35 *Functional diagram of a modified single-stage reducing valve. Note the addition of a poppet closing spring.*
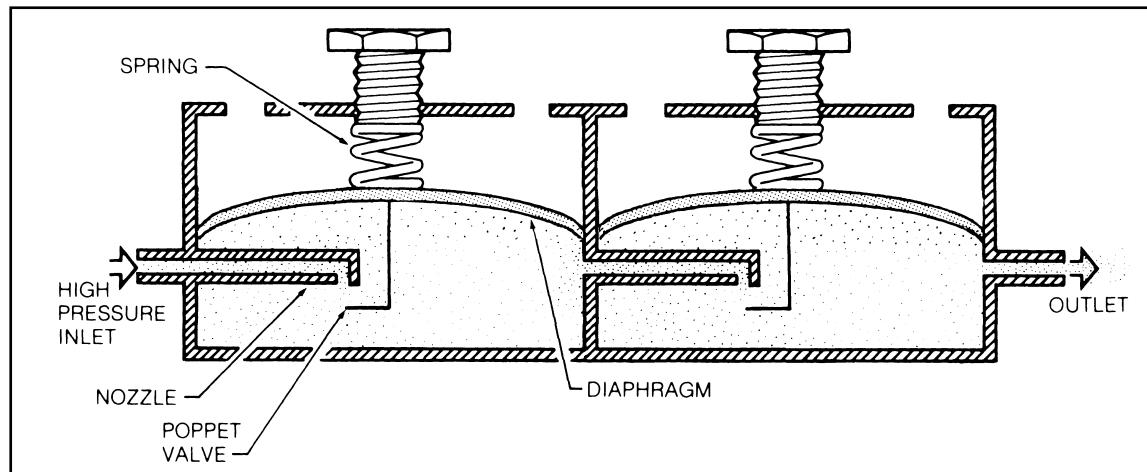
Figure 1-36 *Functional diagram of a two-stage reducing valve. Note how two single-stage regulators are connected in series to form a two-stage regulator.*

REGULATORS

When a flowmeter and a reducing valve are joined together into a common unit, it is termed a **regulator**. Regulators are more convenient than separate reducing valves and flowmeters. Only one high pressure connection is required (between the cylinder and the regulator) and they are more compact in size. A regulator consists of a reducing valve with a Bourdon-type flowmeter, or a reducing valve with a Thorpe tube flowmeter. Both of these flowmeters are discussed later in this chapter.

ASSEMBLY AND TROUBLESHOOTING

### Assembly—Oxygen Reducing Valves

Follow the suggested guidelines when assembling a reducing valve for use.

1. Select a reducing valve appropriate for the intended use. If high flow rates are desired (80–120 liters/min.), use a two-stage or modified single-stage reducing valve.

2. Remove the protective valve cap ("H" cylinder) or protective tape ("E" cylinder) and "crack" the tank by opening and closing the valve quickly to expel any foreign material. Perform this task with the valve pointing away from yourself and other people.

3. Attach the reducing valve to an appropriate cylinder valve (American Standard fitting or Pin Index fitting).

4. Attach the oxygen equipment to the reducing valve.

5. Turn on the cylinder valve.

Troubleshooting

Troubleshooting a cylinder and reducing valve primarily involves checking for leaks. The following is a suggested troubleshooting algorithm (ALG 1-5).

1. Check for leaks at the connection to the cylinder. If leaks are present, tighten the connection.

2. Check for leaks between the reducing valve and the oxygen therapy equipment and tighten as appropriate.

3. If gas fails to flow from the cylinder, check the pressure gauge to ensure that the cylinder has pressure.
   a. If the cylinder contains pressure, check the reducing valve outlet for obstructions.
   b. If the above is satisfied, replace the reducing valve with another and try again.
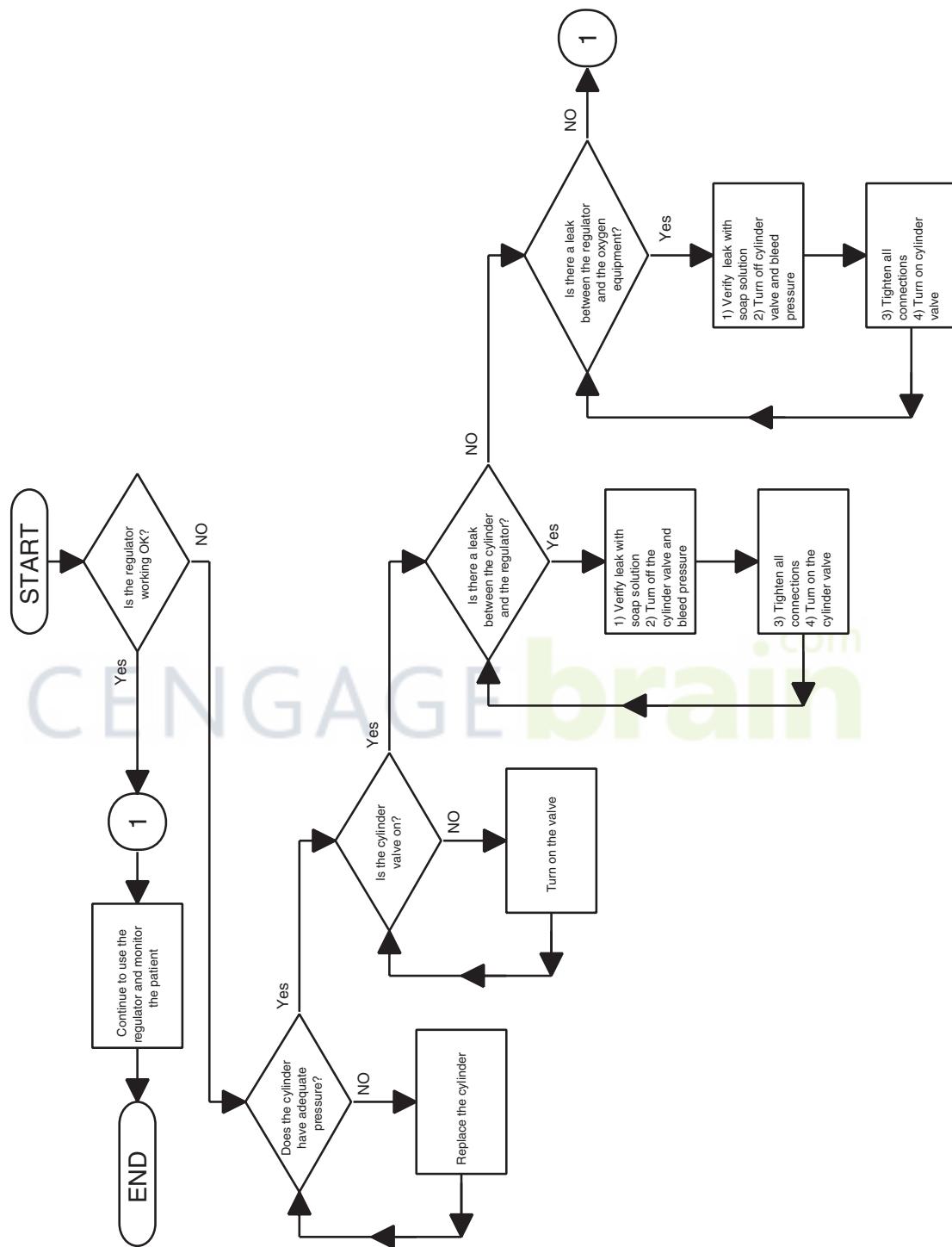
ALG 1-5 *An algorithm describing how to troubleshoot medical gas regulators and reducing valves.*

PROPORTIONERS (AIR-OXYGEN BLENDERS)

Blenders are devices that mix air and oxygen to precise concentrations. These devices provide a stable 50 psi source of mixed gas. Common applications of blenders include, but are not limited to, powering ventilators, Continuous Positive Airway Pressure (CPAP) systems, and controlled oxygen therapy. Blenders are very compact and convenient to use, requiring a 50 psi source of oxygen and air.

Principle of Operation

Air and oxygen entering the blender are first directed into two chambers on opposite sides of a diaphragm that balances the air and oxygen pressures (regulator section). If the incoming pressures are unequal, the regulator portion of the blender balances the pressures so that they are equal (Figure 1-37).

It is important that the pressures are equal, because if one gas entered the proportioning valve at a greater pressure, more of that gas would be delivered, altering the percentage from what is desired.

Gas exiting from the regulator section then passes through a proportioning valve. The oxygen percentage control adjusts the proportions of air and oxygen. If 80% oxygen is desired, turning the control opens the oxygen side more while proportionally closing the air side.

Most manufacturers incorporate a built-in alarm system into the blender. If gas pressure from the supply lines (air or oxygen) drops within the regulation section, an audible alarm will sound.
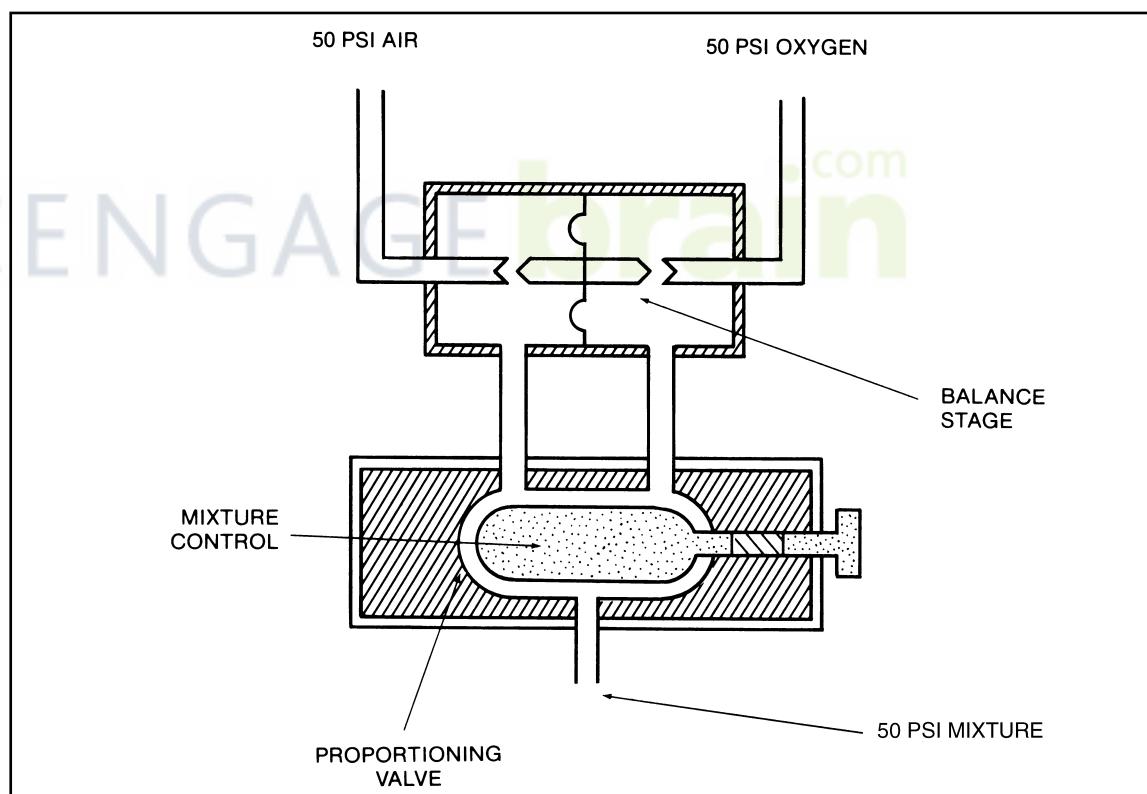
Figure 1-37 *A functional diagram of an oxygen blender.*

ASSEMBLY AND TROUBLESHOOTING

Assembly—Oxygen Blenders

To prepare a blender for use, follow the instructions listed below.

1. Ensure a supply of compressed oxygen and air at 50 psi. The supply devices may include an oxygen piping system or cylinders with appropriate regulators.

2. Connect a 50-psi hose to the air supply and to the air inlet fitting on the blender.

3. Connect a 50-psi hose to the oxygen supply and to the oxygen inlet on the blender.

4. Read the pressure gauges on the blender to verify line pressure (if provided).

5. Check the pressure alarm by disconnecting the air or oxygen source.

6. Adjust the blender to the desired F_IO_2 (fraction of inspired oxygen).

7. Attach the oxygen therapy device or other medical equipment to the outlet of the blender.
   a. If the outlet does not have a one-way check valve, attach the equipment to the blender before attaching the oxygen and air supply lines.

8. Verify oxygen concentration with an oxygen analyzer.

Troubleshooting

Troubleshooting a blender consists of checking for leaks and verifying oxygen concentration. The following is a suggested algorithm (ALG 1-6).

1. Sources of leaks:
   a. Between the gas source (piping system or regulator) and the high pressure hoses.
   b. Between the high pressure hoses and the blender.
   c. Between the blender and the oxygen equipment.

2. Verify the oxygen concentration using an oxygen analyzer. If there is a tremendous discrepancy (greater than ±2%), calibrate the analyzer and repeat verification. If the discrepancy still exists, replace the blender and have the defective unit repaired by your local vendor or authorized biomedical repair facility.
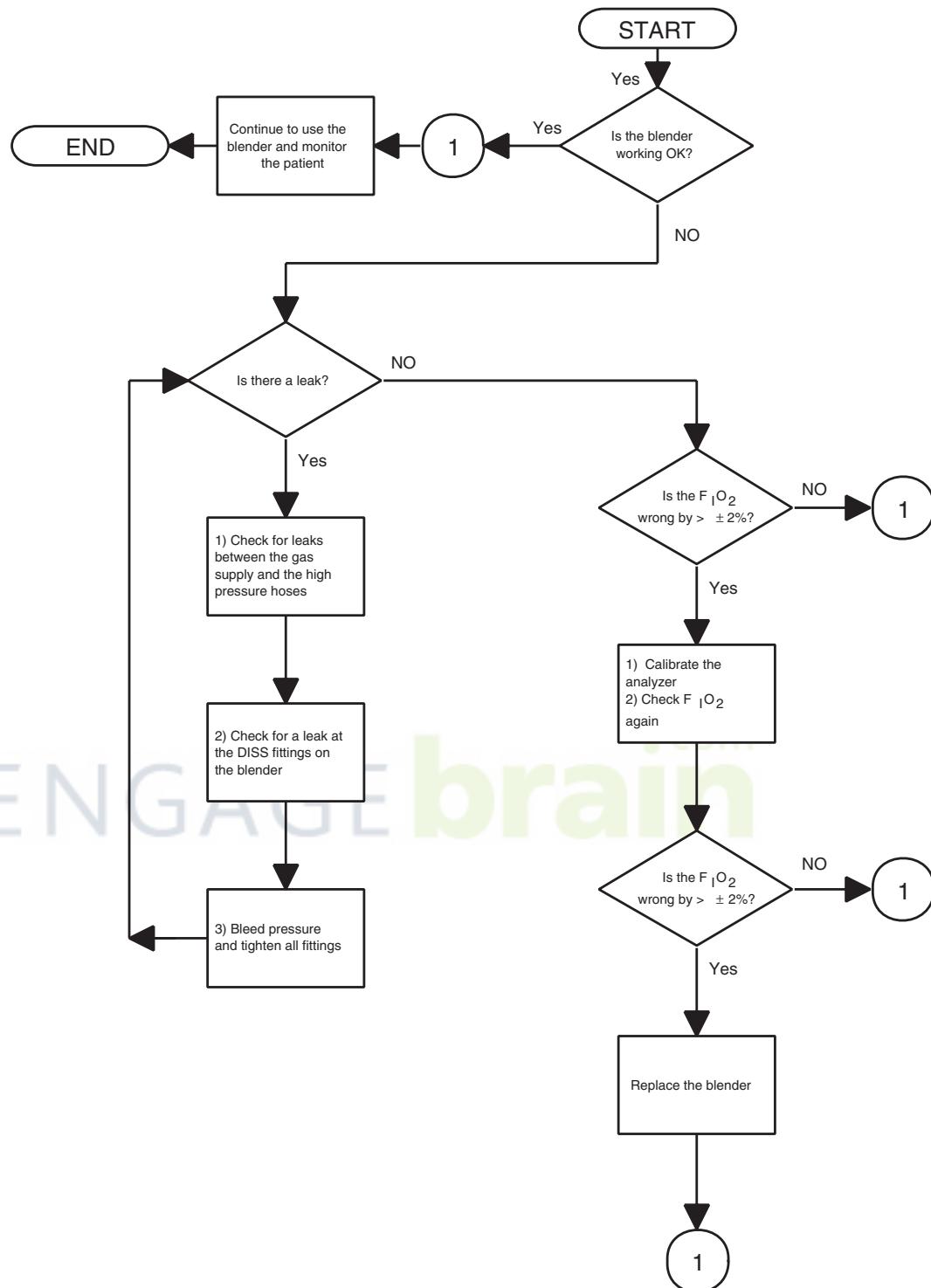
ALG 1-6 *An algorithm describing how to troubleshoot an oxygen blender.*

OXYGEN FLOWMETERS

Bourdon Gauge (Fixed Orifice Flowmeter)

A **Bourdon gauge flowmeter** consists of a Bourdon gauge and an adjustable reducing valve (Figure 1-38). Gas flows through the adjustable reducing valve, past the Bourdon gauge, and then passes through a fixed orifice distal to the Bourdon gauge. The adjustable reducing valve can vary the pressure between the reducing valve outlet and the fixed orifice. As pressure increases, flow out of the device also increases. The increase in pressure between the reducing valve outlet and the fixed orifice causes the coiled tube in the Bourdon gauge to straighten. The gauge, however, is recalibrated to indicate flow rather than pressure as the coiled tube straightens (employing Poiseuille's law).

This flowmeter is accurate as long as the outlet is at ambient pressure. Any increase in pressure distal to the fixed orifice will cause this flowmeter to read inaccurately. This can be caused by obstructions to flow or attachment of equipment that causes back pressure

to develop. It is possible to obstruct the outlet and the Bourdon gauge will indicate a flow higher than is being delivered.

The Bourdon gauge flowmeter is light-weight and very compact. Another advantage of this device is that it will operate in any position. The flowmeter will operate in unusual positions because none of the moving parts is gravity dependent. Therefore, it is popular in emergency and transport settings (ambulance, intra-hospital transport, airborne transport).

Any oxygen connecting tubing, or tubing to oxygen administration devices, must be carefully checked for kinks or obstructions. In a noisy, bumpy environment (ambulance or airborne transport), physically touch and follow the tubing with your hands to verify that the tubing has not been obstructed. Stretchers, equipment or other care providers' feet placed on the tubing could obstruct oxygen flow. You can't tell by monitoring the gauge if oxygen is flowing or not!

Fixed Orifice Flowmeters

Fixed orifice flowmeters are designed to provide specific flow rate settings by selecting
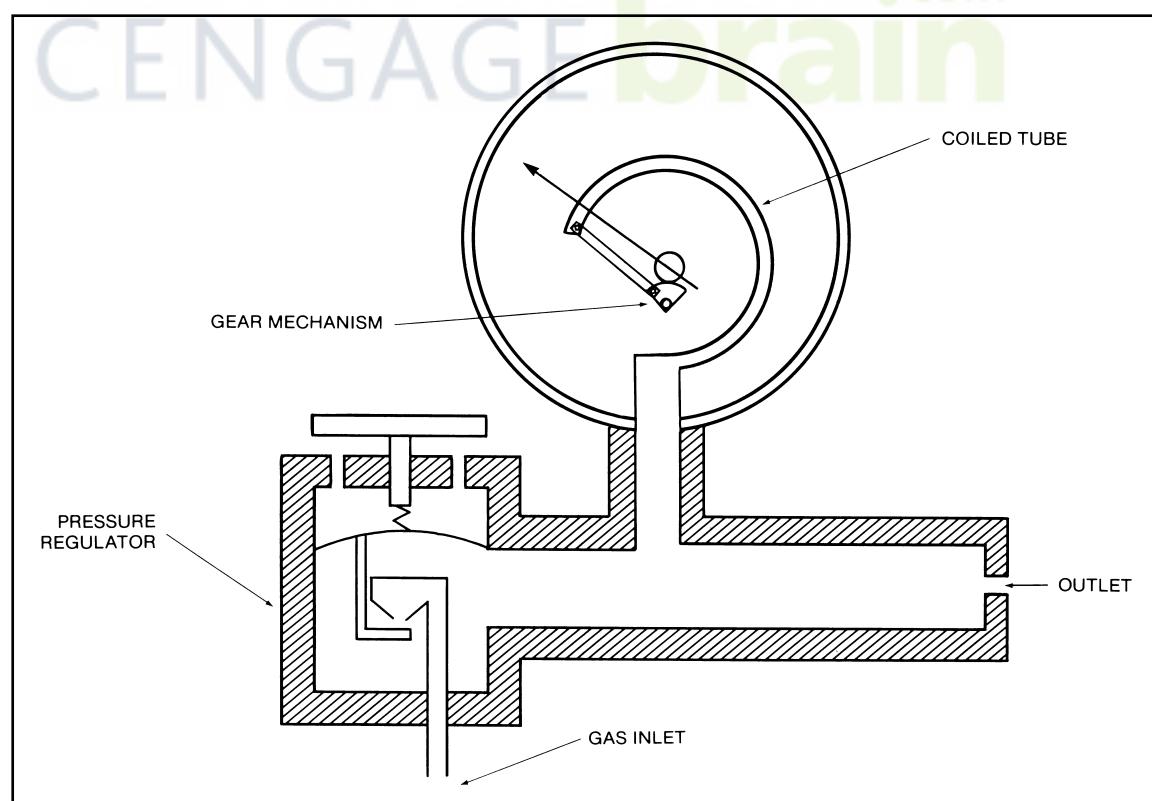
Figure 1-38 *A functional diagram of a Bourdon flowmeter. This is also known as a fixed orifice flowmeter.*

or adjusting an outlet orifice size. At a given inlet pressure, only so much flow can pass through a restricted orifice (choked flow principle). When a large orifice is selected, flow will be high. Conversely, a small orifice will provide a lower flow rate for a given inlet pressure. It is important to use these flowmeters with the correct inlet pressure the flowmeter is designed for (typically 50 psi). Figure 1-39 is an example of a fixed orifice regulator for an E cylinder. This unit incorporates a reducing valve and a fixed orifice flowmeter into a single compact unit.

Uncompensated Thorpe Tube Flowmeter

The components of an uncompensated **Thorpe tube flowmeter** include a "V"-shaped tapered tube (Thorpe tube), a float, and a needle valve (Figure 1-40). Note how the needle valve is positioned proximal to the Thorpe tube.

The Thorpe tube becomes a variable orifice. The Thorpe tube gradually increases in diameter from its base to the top of the tube. The flowmeter is calibrated with the pressure inside of the tube equal to ambient pressure.

Figure 1-40 *An uncompensated Thorpe tube flowmeter.*

The float provides a means of indicating the flow rate. As the needle valve is opened, gas pressure pushes the ball up in the Thorpe tube, overcoming gravity. At equilibrium, gas pressure equals gravitational attraction and the float is stable. As the float moves up in the Thorpe tube, the tube becomes larger and more and more gas flows around it.

The needle valve provides a means of adjusting gas flow into the Thorpe tube. As the needle valve is progressively opened, more gas flows into the tube. The term "uncompensated Thorpe tube flowmeter" refers to the fact that it is uncompensated for back pressure. If pressure is applied distally to the Thorpe tube, for example from a kinked connecting tube or other obstruction, the Thorpe tube becomes pressurized. As the pressure in the Thorpe tube increases, the pressure gradient between the bottom and the top of the float decreases, causing the float to fall. The flow indication may actually be lower than the delivered flow.

Compensated Thorpe Tube Flowmeter

A compensated Thorpe tube flowmeter is similar in design to an uncompensated one

Figure 1-39 *A photograph of a fixed orifice regulator for an E cylinder.*

with one exception. A compensated Thorpe tube's needle valve is distal to the Thorpe tube (Figure 1-41). Since the needle valve is placed distal to the Thorpe tube, pressure within the tube is equal to line pressure or 50 psi when connected to a gas source.

Back pressure applied distally to the needle valve has no effect on its performance. Additional pressure or restriction causes the flowmeter to behave as if the needle valve is closed further, restricting flow. If enough pressure is applied to stop the flow, eventually the pressure proximal and distal to the needle valve will equal 50 psi, the float will no longer be suspended, and gas flow will cease.

When working with Thorpe tube flowmeters, it is often necessary to know if it is compensated or uncompensated. There are three ways to identify a compensated flowmeter:

1. The label will state, "Calibrated at 760 mmHg, 70° F, 50 psig inlet and outlet pressure."

2. With the needle valve closed, the float will rapidly jump up the Thorpe tube when the flowmeter is connected to an oxygen source.

3. Check the position of the needle valve; if it is downstream from the Thorpe tube, it is compensated.

Ranges of Flowmeters

Several manufacturers offer flowmeters with expanded calibration scales that extend beyond the range of the typical 0- to 15-L/min flowmeter's calibrated range. A high-range flowmeter is calibrated from 0 to 75 L/min in 5-L/min units (Figure 1-42A). The high-range flowmeter is useful in Continuous Positive Airway Pressure (CPAP) and high-flow oxygen delivery systems with high-flow clinical applications. Low-range flowmeters have scales calibrated between 0 and 3 L/min in quarter-L/min intervals (Figure 1-42B) and are useful in pediatrics and chronic obstructive lung disease patients.
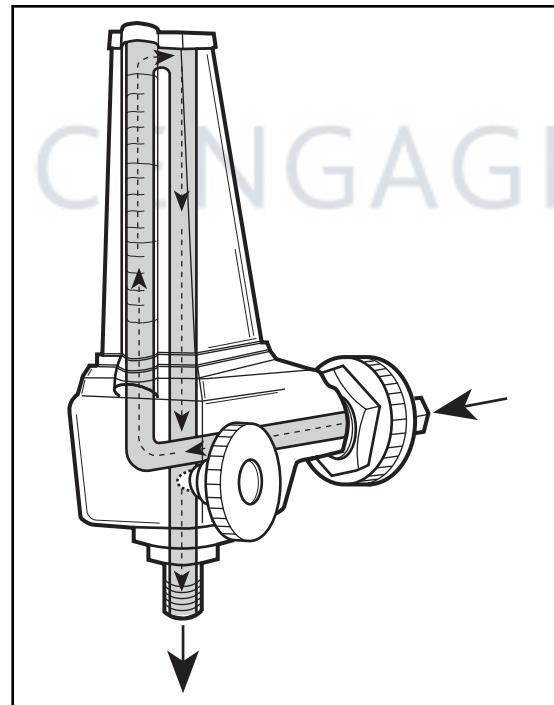
Figure 1-41 *A compensated Thorpe tube flowmeter.*

(A)   **(B)**
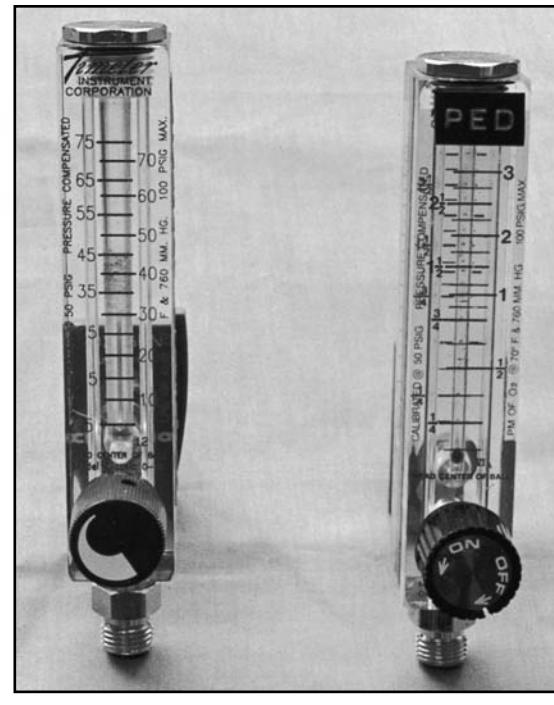
Figure 1-42 *(A) A photograph of a high-range flowmeter, calibrated from zero to seventy-five liters per minute. (B) A photograph of a low-range (pediatric) flowmeter, calibrated from zero to three liters per minute.*

ASSEMBLY AND TROUBLESHOOTING

Assembly—Oxygen Flowmeters

Flowmeters are very easy to assemble for use. Complete the following instructions to prepare a flowmeter.

1. Attach the flowmeter to an appropriate 50-psi gas source using DISS or quick-connect fittings.

2. Attach the appropriate therapy equipment to the DISS fitting on the flowmeter outlet.

3. When using a Bourdon flowmeter, carefully check all supply tubing for kinks or obstructions.

4. Adjust the flow to the desired setting.

5. A Thorpe tube flowmeter can be identified when it is connected to a 50-psi gas source. The float on a Thorpe tube flowmeter will quickly rise and fall when the tube is pressurized to the 50-psi line pressure.

Troubleshooting

Troubleshooting a flowmeter primarily consists of checking for leaks. Periodically, a flowmeter should be checked against a calibration standard for accuracy (calibration flowmeter or volume displacement spirometer). When troubleshooting this equipment, please follow the suggested troubleshooting algorithm (ALG 1-7).

1. Sources of leaks:
   a. Connection between flowmeter and 50-psi gas source.
   b. Connection between flowmeter and the therapy equipment.

2. If the flowmeter fails to deliver expected flow or behaves erratically, check it against a calibration standard and if necessary have it repaired.
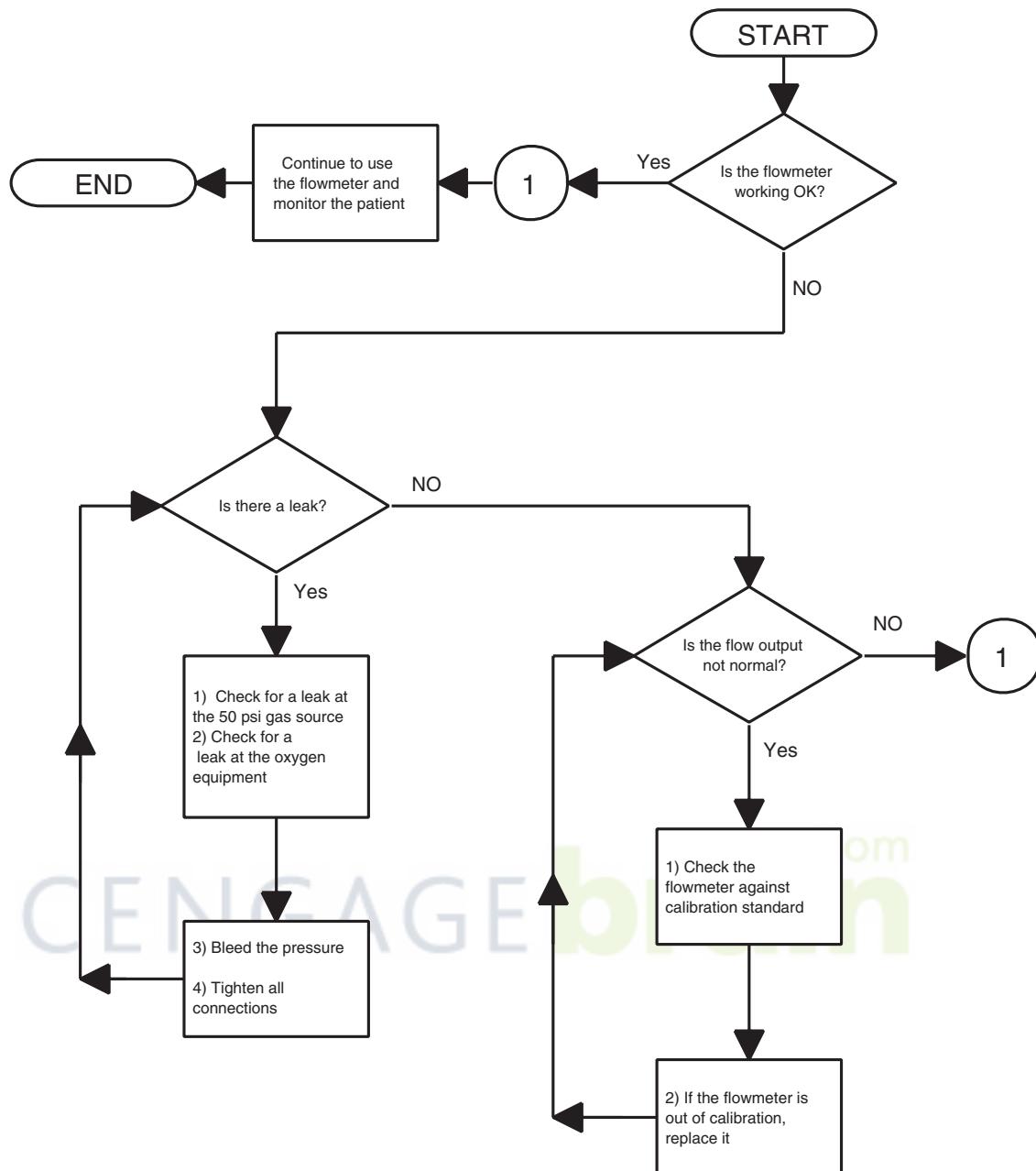
ALG 1-7 *An algorithm describing how to troubleshoot medical gas flowmeters.*

DEMAND PULSE FLOW OXYGEN DELIVERY DEVICES

Demand pulse flow oxygen delivery devices are oxygen delivery devices which are designed to deliver oxygen only during the inspiratory phase. A common name for these devices is an **oxygen conserving device (OCD)**. During a normal ventilatory cycle, when using continuous flow oxygen, oxygen delivered during the last part of inspiration (dead space volume) and the oxygen delivered during exhalation are not usable. Dead space volume is the portion of oxygen delivered which does not participate in gas exchange at the alveoli (Figure 1-43). Demand pulse flow oxygen delivery devices are able to sense the start of the inspiratory phase, and deliver oxygen only during inspiration (Figure 1-44). By delivering oxygen only during that part of the ventilatory cycle that is usable (oxygen
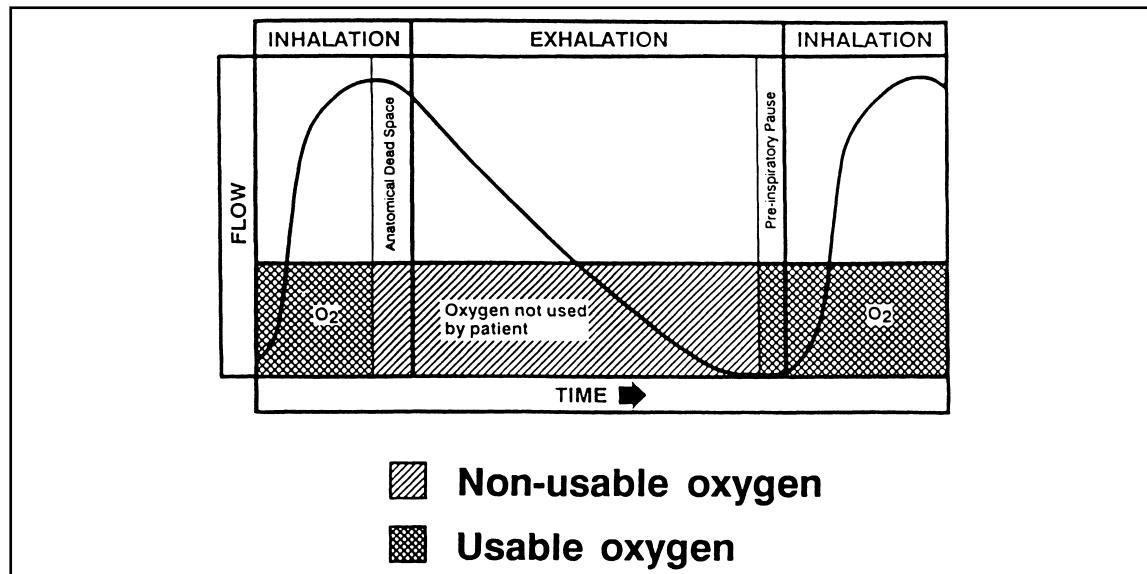
Figure 1-43 *A graph illustrating usable and nonusable oxygen during continuous flow delivery. (Courtesy Puritan Bennett Corporation, Lenexa, KS)*

that can participate in gas exchange), oxygen is conserved when these devices are compared to continuous flow oxygen delivery devices. Since these devices deliver a minimal flow of dry gas, humidification requirements are eliminated. These devices are most commonly used in the home setting, where oxygen conservation can result in substantial cost savings.

When initially setting up an oxygen system on ambulatory patients, it is helpful to perform an exercise oximetry study with both continuous flow and demand pulse flow oxy-gen systems to insure adequate oxygen saturation. Not all patients will be able to maintain adequate oxygen saturations during demand pulse flow delivery. Therefore, it is important to adjust the demand pulse oxygen delivery flow rate to meet the patient's needs during exercise, as documented by oximetry. Some patients with severe pulmonary disease may not tolerate demand pulse flow oxygen delivery systems at all. In these patients, continuous flow oxygen systems are required to maintain adequate oxygen saturations.
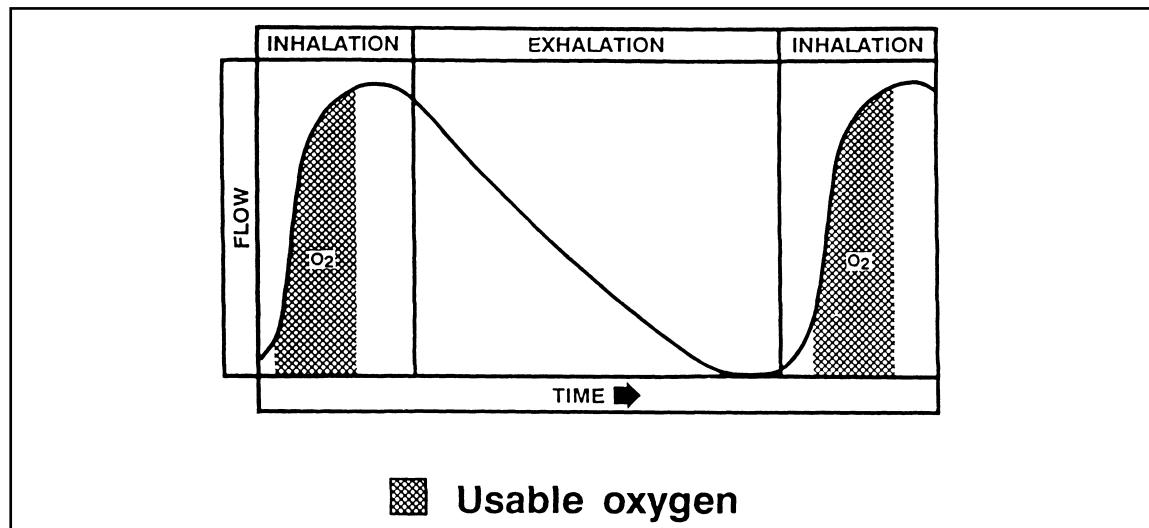

Figure 1-44 *A graph illustrating usable and nonusable oxygen during pulsed demand flow delivery. (Courtesy Puritan Bennett Corporation, Lenexa, KS)*

Transtracheal Systems DOC 2000 Demand Oxygen Controller

The Transtracheal Systems DOC 2000 demand oxygen controller is a pulse demand oxygen delivery device that conserves oxygen by delivering it only during inspiration (Figure 1-45). The unit is electronically controlled and may be powered by a rechargeable Ni-Cad battery or a 120 v, 60Hz power adapter, which also functions to recharge the Ni-Cad battery. When the Ni-Cad battery is fully charged, the DOC 2000 can operate between 8 and 10 hours before requiring a recharge.

Inspiratory Detection

The DOC 2000 detects inspiration using a sensitive pressure transducer. During inspiration, a sub-ambient pressure is created in the patient's nares as the lungs expand. When the pressure transducer senses the drop in pres-

sure, a valve opens, delivering oxygen to the patient.

Oxygen Flow Control

The operation of the DOC 2000 is based upon switching the patient between the oxygen source (valve 2) and the pressure sensor (valve 1). When valve 2 is not energized, oxygen flows from the source directly to the patient (Figure 1-46). Simultaneously, when valve 2 is not energized, valve 1 is energized, which connects the transducer (U11) to the normally closed atmospheric port. Each time the pressure transducer is referenced to ambient pressure, it recalibrates itself, which maintains a consistent sensitivity threshold.

During exhalation, valve 2 is energized, which closes it and stops the flow of oxygen. Valve 1 is not energized, which connects the pressure transducer to the patient through the normally open port of valve 1 (Figure 1-46). Once a pressure drop is detected, valve 2 opens and valve 1 closes, beginning the inspiratory cycle once again.

Monitoring System

The DOC 2000 uses a green light-emitting diode (LED) for two functions. When the unit is first turned on, the LED illuminates and stays on for approximately 1 second, indicating that power is on and that the unit is self-calibrating. Once the patient is connected to the DOC 2000, the green LED will illuminate during inspiration. This tells the operator/user that

Figure 1-45 *A photograph of the DOC 2000 demand oxygen controller. (Courtesy Transtracheal Systems, Englewood, CO)*
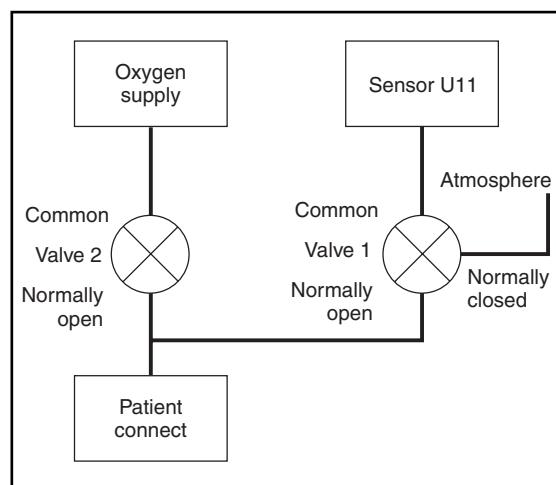
Figure 1-46 *A schematic diagram of the DOC 2000 demand oxygen controller. (Courtesy Transtracheal Systems, Englewood, CO)*

inspiration has been detected and that oxygen flow is initiated.

A yellow LED and audible alarm alerts the operator/user of a low battery level. In the event this alarm system is activated, discontinue battery operation and connect the unit to its AC power pack/charging unit. The Ni-Cad battery can be recharged in approximately 13 hours.

The DOC 2000 also incorporates a system default signal indicator/alarm detector. A red LED illuminates if the unit does not sense an inspiratory effort within approximately 45 seconds. When this occurs, the red LED illuminates and a continuous audible alarm sounds. If an inspiratory effort is detected within 8 to 10 seconds, the unit will reset itself. If no inspiratory effort is detected within approximately 50 seconds, valve 2 opens, delivering the prescribed oxygen flow continuously.

DeVilbiss OMS 20 and EX2000D

DeVilbiss Health Care, Inc., markets two electronically controlled demand pulse flow oxygen delivery devices (Figure 1-47A and B). The OMS 20 is designed to be used with 20 psi liquid oxygen systems. The OMS 20 may be operated from an internal battery for up to 23 hours or by an optional 115 V, 60 Hz power

adapter. The unit senses the patient's inspiratory efforts and delivers a pulse of oxygen during early inspiration. Pulsed oxygen delivery may be provided at flows of between 0.25 and 6 liters per minute.

The EX2000D is designed for use on small oxygen cylinders having a yoke type cylinder valve. The EX2000D is powered by a standard alkaline "C" cell battery. Once the battery is installed, the unit is slipped over the cylinder yoke, and the T-handle is hand-tightened until it seals against the cylinder valve, much like a standard regulator is secured. A selector switch on the right of the unit allows the operator to select between continuous flow and pulsed dose oxygen delivery.

Inspiratory Detection

The DeVilbiss units use a very sensitive pressure transducer to detect the patient's inspiration. As the patient inhales through his or her nasal cannula, the sub-ambient pressure created in the patient's lungs is transmitted to the DeVilbiss unit through the cannula. A sub-ambient pressure (Trigger Level—0.02 cm H_2O) causes an electrical signal to be sent from the pressure transducer (sensor) to the solenoid valve. Once inspiration is detected by the transducer, an electrical signal opens the solenoid valve, delivering a pulse of oxygen.

(A)   (B)
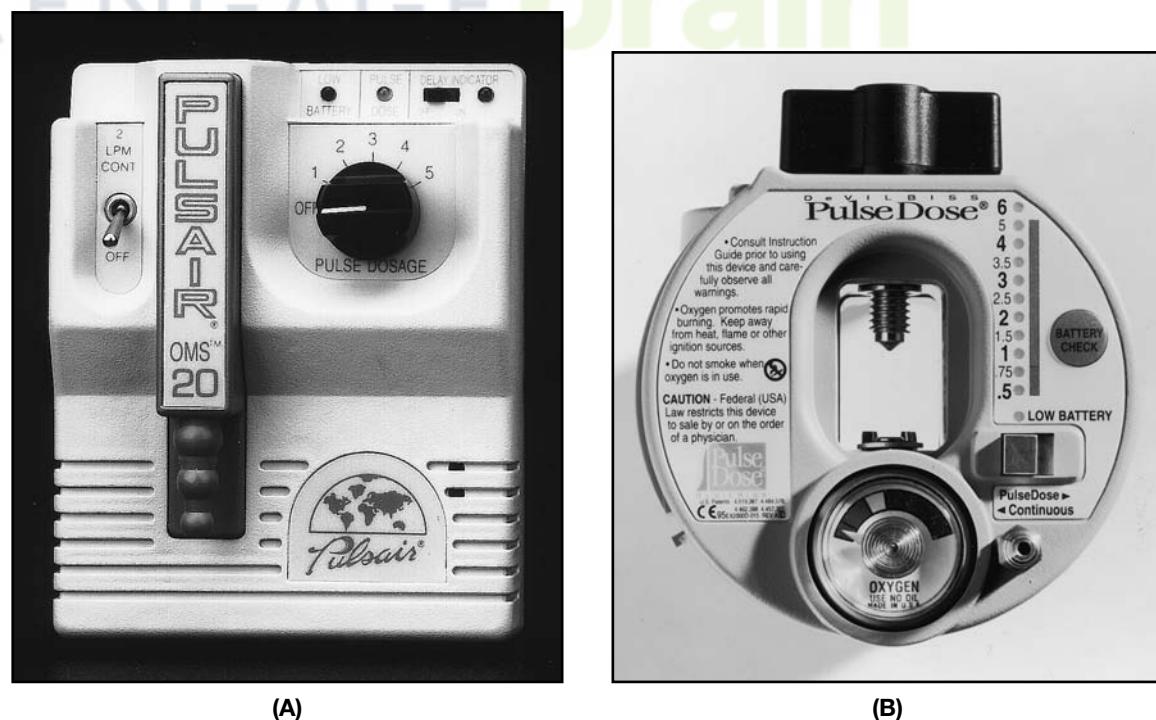
Figure 1-47   *(A) A photograph of the DeVilbiss OMS 20. (B) A photograph of the DeVilbiss EX2000D pulse flow oxygen system. (Courtesy DeVilbiss Health Care, Inc. Somerset, PA)*

Oxygen Flow Control

Oxygen flow (OMS 20) is determined by the setting on the Pulse Dosage switch. The Pulse Dosage switch is a rotary switch which determines how long the solenoid valve remains open. As the flow rate setting is increased by turning the Pulse Dosage switch, the time the solenoid valve remains open is also increased. This is a time-based variable circuit with a constant flow rate. The volume of oxygen delivered to the patient is solely determined by the amount of time the solenoid valve remains open. Therefore, when the respiratory rate increases, the patient actually receives more oxygen. This would be referred to as a "rate response" type of oxygen delivery.

Liter flow on the EX2000D is adjusted by connecting the unit to a cylinder and by attaching a short length of tubing between the EX2000D and an external flowmeter used for calibration purposes. An Allen wrench is inserted into the fitting on the bottom of the EX2000D, and flow is adjusted until the desired flow is displayed on the external flowmeter. Once the desired flow is set, the wrench is removed, along with the calibration flowmeter and connecting tubing.

Monitoring Systems

The DeVilbiss OMS 20 and EX2000D have several monitoring features built into the units. These features include low battery detection, pulse delivery indication and a detection delay indicator.

The low battery indicator will light and an audible alarm will sound when the battery power becomes low. When this condition is detected, it is important to recharge the internal battery using the 120 V, 60 Hz adapter supplied with the unit.

During inspiration, a green LED will illuminate when a pulse is delivered. The sensor circuit sends an electrical signal to illuminate the LED simultaneously with the signal sent to the solenoid valve. Whenever the solenoid valve is opened, the green Pulse Dose LED is also illuminated for the duration of the valve's open time.

A detection delay system is also incorporated into the design of the DeVilbiss units. If an inspiratory effort is not detected within a specified time interval (the time interval is adjustable from 6 to 60 seconds), a red LED will illuminate and a continuous audible alarm will sound. This feature may be turned "ON" or "OFF" by using the two-position Delay Detector switch.

Chad Therapeutics Oxymatic 301 and Oxymatic 2400

Chad Therapeutics, Inc. has designed and is marketing two electronic demand flow pulse delivery oxygen conserving devices (Figure 1-48). The model 301 is designed for portable operation (intermittent), and the model 2400 is designed for continuous use, although it may also be used with portable
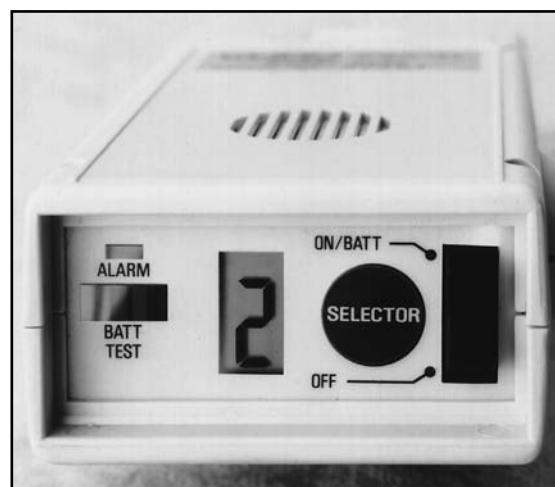
Figure 1-48 *Photographs of (A) the Chad Therapeutics Oxymatic 301 and (B) Oxymatic 2400 pulse flow oxygen delivery systems. (Courtesy Chad Therapeutics, Inc., Chatsworth, CA)*

oxygen systems. Both units electronically sense the end of expiration and the beginning of inspiration and deliver a pulse of oxygen within .2 seconds following the start of inspiration. Both units are powered by common alkaline "C" size batteries. The battery life averages 3 to 4 weeks of use.

Inspiratory Detection

During inspiration, a sub-ambient pressure is created in the lungs as the lungs expand. During exhalation, chest wall recoil creates a pressure in the lungs that is greater than ambient pressure. These very small pressure changes are communicated to the Oxymatic units through the patient's nasal cannula.

The Oxymatic units have an internal flexible diaphragm that changes position in response to the pressure changes in the patient's lungs. The neutral position (position between exhalation and inspiration) is electronically detected. When diaphragm motion away from the neutral position is detected, inspiration is detected. An electronic signal is transmitted to the solenoid valve, opening it and delivering a 35-mL pulse of oxygen within 0.2 seconds of the start of inspiration.

Oxygen Flow Control

The Oxymatic units deliver a constant 35-mL pulse of oxygen when the solenoid valve opens. The units control oxygen flow delivery by altering how frequently these constant volume pulses are delivered.

Clinical trials have shown that when the Oxymatic units deliver 35-mL pulse of oxygen every breath, this is equivalent to a continuous oxygen flow of 4 L/min (determined by oxygen saturation). When a pulse is delivered three out of every four breaths (75% of the time), this is equivalent to a continuous flow of 3 L/min. When a pulse is delivered every other breath (50% of the time), this is equivalent to 2 L/min continuous flow. When oxygen is delivered one out of every four breaths (25% of the time), this is equivalent to 1 L/min continuous flow.

Because of the unique pulse delivery (alternate breath delivery below 4 L/min), some patients may be uncomfortable initially when using these units. It is important to explain how these units work and that even though the patient may not feel oxygen flow on each breath, it is equivalent to what they have been receiving. As noted earlier in this section, it is important to conduct an oximetry trial to determine the oxygen needs of a patient who is using a conserving device.

Monitoring Systems: Oxymatic 301

The monitor on the Oxymatic 301 is a battery test indicator. To use the battery tester, move the thumbwheel selector on the top of the unit to the "Battery Test" position. Observe the indicator to assess the battery's condition. If the indicator is red, replace the battery before use. If the indicator is amber, you should have a replacement battery available to use. If the indicator is green, the battery has sufficient electrical energy to operate the unit. The Oxymatic 301 uses a common alkaline "C" size battery.

Monitoring Systems: Oxymatic 2400

The Oxymatic 2400 has a battery test feature, a low battery warning indicator and an apnea alarm. All of these conditions can be monitored on the top of the unit. The battery test can be performed by moving the black rocker switch to the "ON/BATT" position while the unit is on. The "BATT TEST" display will indicate the battery's condition. If the display is dark green, the battery is in good condition. With use, the color of the green indicator becomes progressively lighter. When the display is amber in color, approximately 48 hours of battery life remains. If the indicator is red, 24 hours of life remains and the battery should be changed.

The low battery warning is a blinking LED display in the Indicator Setting window that resembles a battery. When the battery life falls to around 24 hours of continuous use, the low battery warning will flash intermittently. When this condition is observed, the battery should be changed as soon as possible.

Apnea detection is built into the Oxymatic 2400. If the unit fails to sense inspiration over a period of 40 seconds, the alarm system is activated. An audible and visual alarm will alert the user to this condition. A flashing red light labeled "ALARM" on the top of the unit will flash intermittently along with the audible alarm. Besides apnea, kinks in the patient's tubing or patient disconnects can also cause this alarm.

ASSEMBLY AND TROUBLESHOOTING

Assembly—Oxygen Conserving Devices

1. Connect the conserving device to an oxygen source (cylinder or liquid system).

   a. An oxygen cylinder requires the use of a regulator to reduce the cylinder pressure and to set the oxygen delivery to the prescribed flow. The conserving device is attached to the outlet of the regulator.

   b. A liquid system requires the use of a flowmeter, which is used to set the desired flow rate. The conserving device is attached to the outlet of the flowmeter.

   c. A portable liquid reservoir may also be used by threading a barbed hose-fitting adapter into the inlet port of the conserving device and attaching the other end to the outlet of the portable reservoir set at the appropriate flow rate.

2. Connect the delivery tubing of the nasal cannula or transtracheal catheter to the barbed outlet of the conserving device. Delivery tubing should never exceed 35 feet in length.

3. Depress the "On/Off" button on the top of the unit to turn the unit on. The unit will perform a self-calibration (about 1 second) and then will operate normally.

Troubleshooting

When troubleshooting oxygen conserving devices, please follow the suggested troubleshooting algorithm (ALG 1-8).

1. If the unit fails to deliver oxygen flow:

   a. Check tubing and cannula or transtracheal catheter for obstructions or kinks.

   b. Make certain that the oxygen flowmeter is on and that there is a sufficient quantity of oxygen (pressure for cylinders or weight for liquid systems).

   c. The patient may not be generating a sufficient inspiratory effort to activate the inspiratory detection circuit. Patients with advanced lung disease may not be candidates for pulsed oxygen delivery and may require continuous flow.

   d. Verify that the batteries are in good condition and are in place if the unit is battery powered.

START

Is the unit operating OK?

Yes

1

Continue to use the device and monitor the patient

END

NO

Is oxygen flowing?

NO

Is the cannula obstructed?

NO

Is the cylinder valve on?

NO

Can the patient trigger gas flow?

Yes

1

Yes

Clear obstruction or replace cannula

Yes

Turn on the cylinder valve

No

Consider using a different device

Is the unit getting power?

Yes

Are the batteries good?

Yes

1

NO

Replace the batteries

ALG 1-8 *An algorithm describing how to troubleshoot an oxygen conserving device.*

CLINICAL CORNER

Medical Gas Supply Equipment

1. You are on-call for a home care company that employs you as a respiratory care practitioner. A patient who was just set up at home on a liquid oxygen system calls with a complaint. Over the phone, Mr. Smith says: "My new oxygen bottle is hissing. I am worried it might explode." What should you tell your new client, and what would you recommend that he do?

2. You are preparing to transport a patient from the intensive care unit (ICU) to the floor. In order to do so, you set up an "E" cylinder to provide oxygen to his cannula. When you turn on the cylinder valve, you hear a leak. Describe the steps you would take to correct the problem.

3. You are setting up a new patient at home with an oxygen concentrator. The patient requests that she be allowed enough freedom of movement to reach the bathroom, the kitchen, and her bedroom (the location of the concentrator). Describe how you would evaluate the concentrator's placement and any limitations you might impose regarding maximum lengths of extension tubing.

4. Describe a clinical situation in which you might select a single-stage reducing valve and another in which you might select a two-stage reducing valve.

5. You are evaluating a patient for a pulsed demand regulator for his portable oxygen system. Describe how you would appropriately evaluate him, state which of the devices discussed in the text is best for a given patient, and explain why.

6. You are using a Bourdon gauge flowmeter for a helicopter transport. What safety precautions should you be aware of when using this type of regulator?

Self-Assessment Quiz

1. "Gases being composed of discrete molecules in random motion" best describes:
   a. the ideal gas law.
   b. the kinetic theory of gases.
   c. Dalton's law.
   d. Charles' law.

2. The kinetic activity of gases is largely dependent upon:
   a. their concentration.
   b. the pressure.
   c. the temperature.
   d. the type of gas.

3. Chambers A and B are connected by high-pressure tubing and separated by a valve. If chamber A contains 500 psi of gas and chamber B contains 50 psi of gas, what will occur when the valve is opened?
   a. The pressures in the chambers will remain equal.
   b. Chamber A will be pressurized by chamber B.
   c. Gas will flow from chamber A to chamber B until pressures equalize.
   d. The pressure in chamber B will increase to a level greater than in chamber A.

4. Pascal's law best describes:
   a. the relationship between volume and pressure of a gas.
   b. the relationship between pressure and temperature of a gas.
   c. the relationship between temperature and volume of a gas.
   d. the equal distribution of pressure transmitted by a fluid.

5. A device used clinically to measure small pressures is termed a:
   a. mercury barometer.
   b. aneroid barometer.
   c. manometer.
   d. reducing valve.

6. A Bourdon gauge:
   I. uses a coiled tube.
   II. uses a sealed diaphragm.
   III. measures pressure.
   IV. measures flow.
   a. I and II
   b. I and IV
   c. II and III
   d. II and IV

7. The statement, "As temperature increases, pressure also increases," best describes:
   a. Gay-Lussac's law.
   b. Dalton's law.
   c. Henry's law.
   d. Charles' law.

8. Bernoulli's theorem best describes:
   a. the relationship between temperature and pressure of a gas.
   b. the relationship between volume and pressure of a gas.
   c. an energy balance or conservation between velocity and pressure.
   d. the relationship between pressure of a gas and its ability to dissolve into a liquid.

9. An air entrainment mask operates by mixing source gas (oxygen) and room air. This device operates using:
   a. viscous shearing and vorticity.
   b. Bernoulli's theorem.
   c. Venturi's principle.
   d. Poiseuille's law.

10. You are analyzing the F_IO_2 of a patient's HAFOE device, which reads 0.85. The entrainment port is set at 40%. Why would the analyzed oxygen concentration differ so much from the setting?
    a. The analyzer is malfunctioning.
    b. The patient's respiratory rate is affecting oxygen delivery.
    c. More room air is being entrained.
    d. There may be an obstruction distal to the entrainment port.

11. A gas's velocity is said to be choked when:
    a. velocity can no longer increase.
    b. a maximum temperature is reached.
    c. pressure is at a maximum.
    d. the concentration is at a maximum.

12. A patient with reactive airway disease is experiencing bronchospasm. The patient's work of breathing has dramatically increased in the last few minutes. This is an example of:
    I. Poiseuille's law.
    II. the Bernoulli theorem.
    III. increased airway resistance.
    IV. decreased lateral pressure.
    a. I and III
    b. I and IV
    c. II and III
    d. II and IV

13. You measure the volume of gas exiting a delivery device at 22 degrees Celsius to be 1.50 liters. The gas passes through a heater, warming it to 37 degrees Celsius. What is the actual volume delivered to the patient?
    a. 1.56 liters
    b. 2.00 liters
    c. 2.50 liters
    d. 3.12 liters

14. "The rate of gas diffusion into or out of a liquid is directly proportional to the partial pressure of the gas" best describes:
    a. Charles' law.
    b. Fick's law.
    c. Henry's law.
    d. Gay-Lussac's law.

15. Given the following gas mixture:
    Gas A = 20%
    Gas B = 50%
    Gas C = 30%
    Total pressure equals 600 mmHg.
    Find the partial pressure of Gas A.
    a. 10 mmHg
    b. 20 mmHg
    c. 80 mmHg
    d. 60 mmHg

16. Which of the following is constructed in a similar way to a thermos bottle?
    a. oxygen cylinder
    b. oxygen concentrator
    c. liquid oxygen reservoir
    d. oxygen piping system

17. Safety features incorporated into regulators or reducing valves include:
    I. DISS outlet.
    II. PISS inlet.
    III. American Standard inlet.
    IV. pressure relief valve(s).
    a. I only
    b. I and II only
    c. I, II, and III only
    d. I, II, III, and IV

18. Which of the following is (are) true for an "H" size oxygen cylinder?
    I. When full, it contains 2,200 psi.
    II. It contains 22 cubic feet of gas.
    III. It will have "3AA" stamped on the shoulder.
    IV. It contains 244 cubic feet of gas.
    a. I and II only
    b. I and III only
    c. I, III, and IV only
    d. I, II, and III only

19. The marking "3AA" indicates:
    a. the cylinder type.
    b. the contents of the cylinder.
    c. the cylinder serial number.
    d. the cylinder size.

20. The lightest compressed gas cylinder for ambulatory use is:
    a. a 3AA steel cylinder.
    b. an aluminum (3AL) cylinder.
    c. a fiber wrapped cylinder.
    d. a portable liquid reservoir.

21. A device that mixes air and oxygen is termed a (an):
    a. concentrator.
    b. oxygen enricher.
    c. oxygen proportioner.
    d. reducing valve.

22. When troubleshooting an oxygen concentrator, you find that the device is operating yet you are unable to obtain the desired flow of oxygen-enriched gas. Possible problems include:
    I. a tripped circuit breaker.
    II. obstructed delivery tubing.
    III. obstructed humidifier.
    IV. a dirty filter.
    a. I
    b. I and II
    c. II and III
    d. I and IV

23. Advantages of transfilling portable cylinders from a home oxygen concentrator include:
    I. convenience.
    II. cost savings.
    III. speed of filling the cylinder.
    a. I only
    b. I and II
    c. I and III
    d. I, II, and III

24. When making a call on a home care patient, you weigh her liquid reservoir, which registers 80 lbs. You know the manufacturer's weight to be 60 lbs, and that your patient uses 3 L/min oxygen. How much gas does her reservoir contain, and can she wait for 5 hours before your company's delivery truck arrives?
    I. 12,340 L oxygen remaining
    II. 5,484 L oxygen remaining
    III. 30 hours' duration remaining
    IV. 84 hours' duration remaining
    a. I and III
    b. I and IV
    c. II and III
    d. II and IV

25. An advantage of using a demand pulse flow oxygen delivery system in the home care environment is that:
    I. less oxygen is used.
    II. it is less expensive for the patient.
    III. a humidifier is not required.
    a. I
    b. II
    c. I and II
    d. I, II, and III

26. When selecting an oxygen conserving device for ambulatory use, it is important to:
    a. select the unit based upon overall cost.
    b. perform an ambulatory oxygen saturation trial using the unit.
    c. draw arterial blood gases before and after ambulation.
    d. none of the above.

27. A potential disadvantage to the Mallinckrodt Puritan Bennett® HELiOS® system is:
    a. it is heavier than other portable liquid reservoirs.
    b. it has a smaller capacity than competing units.
    c. it must be used with the HELiOS7 dual lumen cannula.
    d. it can only provide flow rates of up to 2 L/min.

28. Back pressure will affect the accuracy of which of the following flowmeters?
    I. Compensated Thorpe tube
    II. Uncompensated Thorpe tube
    III. Bourdon flowmeter
    a. I and II only
    b. II and III only
    c. I and III only
    d. III only

29. A back pressure compensated flowmeter:
    I. reads correctly if back pressure is applied.
    II. reads lower than the actual flow when back pressure is applied.
    III. has the needle valve downstream from the Thorpe tube.
    IV. has the needle valve upstream from the Thorpe tube.
    a. I and III
    b. I and IV
    c. II and III
    d. II and IV

30. When using a fixed orifice flowmeter, it is important to:
    a. calibrate it using a calibration flowmeter.
    b. use the correct inlet pressure.
    c. ensure that there isn't a restriction in the inlet tubing.
    d. adjust the regulator to the pressure on the label.

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APPENDIX

ANSWER KEYS TO SELF-ASSESSMENT QUESTIONS

Chapter 1 • Medical Gas Supply Equipment

1. b	6. a	11. a	16. c	21. c	26. b
2. c	7. a	12. a	17. e	22. c	27. c
3. c	8. c	13. a	18. d	23. b	28. b
4. d	9. a	14. c	19. c	24. c	29. a
5. c	10. d	15. e	20. c	25. b	30. a

This page contains answers for this chapter only.